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FINAL REPORT

"A STUDY OF GEOGRAPHICAL DISTRIBUTION OF GEOMAGNETIC MICROPULSATIONS"

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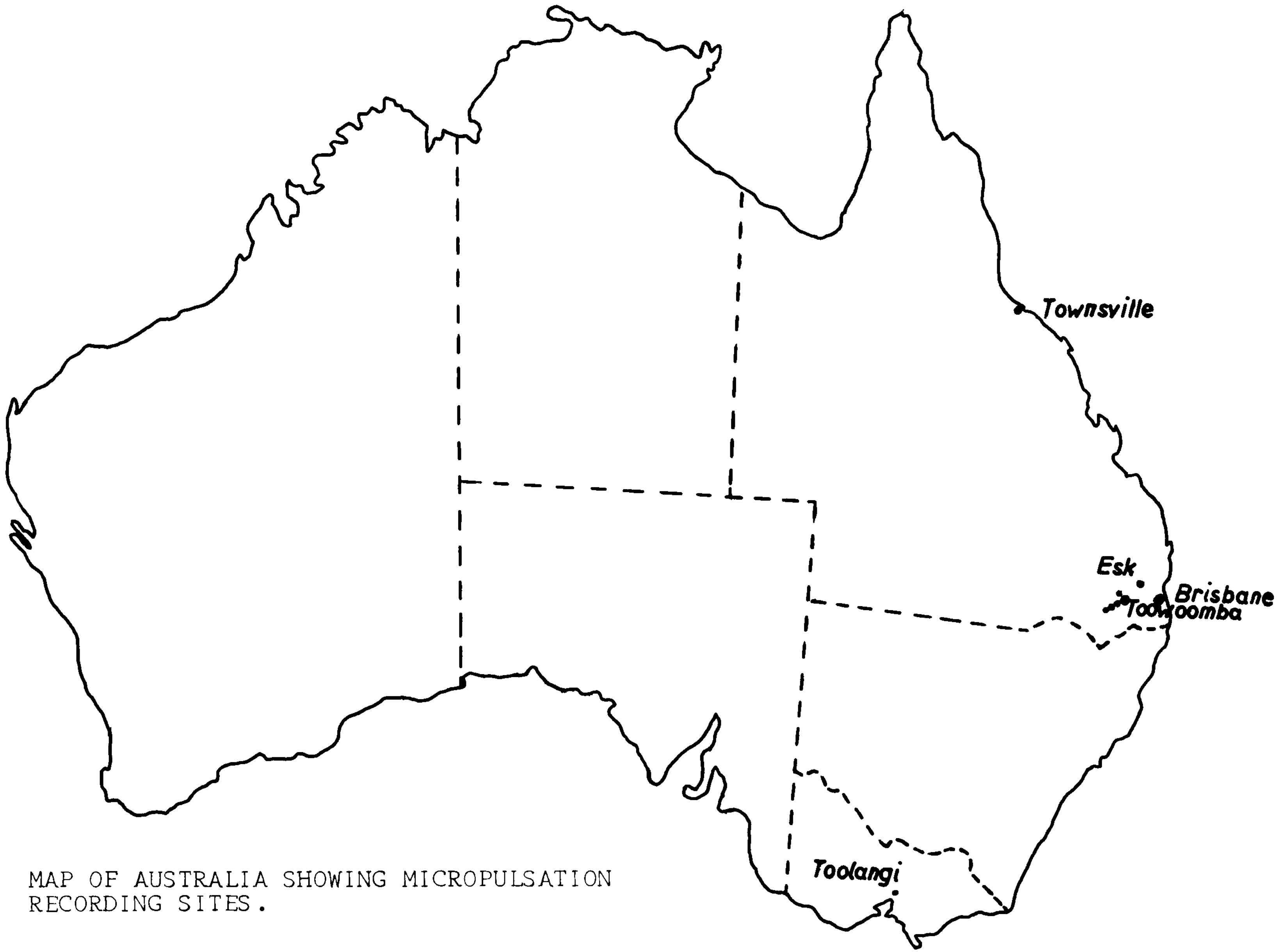
NOVEMBER, 1966



MAP OF AUSTRALIA SHOWING MICROPULSATION RECORDING SITES.

CONTENTS

I

FINAL REPORT, NOVEMBER 30, 1966.

The project entitled "A Study of Geographical Distribution of Geomagnetic Micropulsations" involves a co-operative data recording program with Boeing Scientific Research Laboratories in Seattle, and a supply to NASA in digital form of a certain amount of the recorded data, namely that portion of the observing period which contains information of interest.

In April, 1966, a program of continuous recording of geomagnetic micropulsations in three orthogonal components (Hx, Hy, Hz) was commenced and, apart from occasional interruptions due to equipment failure, continued until July. Subsequent to that date, and continuing up to the present time (November 1966), recordings were made only of the two components in the horizontal plane, i.e. Hx and Hy, the vertical component Hz having to be omitted because of unreliability of the chopper amplifiers.

The accuracy of the data recording on frequency-modulated magnetic tapes has been checked by playing back and demodulating a number of lengthy samples and making chart recordings of the fluctuations and comparing these with chart recordings made directly from the amplifier outputs at the field station. These comparisons showed that the original signals were being recovered from the magnetic tapes in a quite satisfactory way.

Details of the frequency-demodulator and digitizer, and associated sample-hold circuitry, (for simultaneous rather than sequential sampling of the independent signals coming from the three orthogonal components of the micropulsations), are given in a separate section of this report, as is a description of the improved standardising and calibrating procedures which have been developed and employed during part of the recording period. Also a section is included on a precision timing system which has been designed and tested but not yet constructed in its final form or put into operation. Since a considerable amount of recorded data on micropulsations has been accumulated in the past eight months it is now proposed to attempt to carry out some analysis of such features as power spectra, phase propagation from point to point as a function of fluctuation frequency, and coherency between spaced stations. An indication of the computer programs to be applied is included in the later sections of this report.

During the period of currency of the NASA grant, the Radio Research Board of Australia organised a symposium on geomagnetic micropulsations at Hobart, Tasmania (in August 1965). Since the content of one of the review papers prepared by a member of the Queensland University micropulsation group is directly relevant to the work of this group under the NASA research grant, a copy of the paper is included in this report. In addition, a study of the frequency spectra of micropulsations recorded at sites in Eastern Australia is appended, as well as a description of the progress to date of some work done by members of the group on the small-scale geographical distribution of micropulsations, and their dependence on the local geology of the recording site.

II

DETAILS OF AUXILIARY EQUIPMENT

1. RECONSTRUCTION OF ANALOG SIGNALS FROM MAGNETIC TAPES AND SUBSEQUENT DIGITIZATION.

I.M. Brazier and R.E. Dunlop

Three components of micropulsation signal, in the frequency range 5 to 100 mHz, induced into magnetic pick-up coils, have been recorded simultaneously on magnetic tape moving at the rate of $67\frac{1}{2}$ inches per hour in the form of frequency modulation of a 10Hz carrier. The fourth track on the magnetic tape has been used to record an unmodulated 10Hz carrier. For timing purposes a calibration 50 mHz signal was added to the micropulsation signal channels for one minute every hour and for twenty minutes starting at midnight.

Demodulation of Tapes

These tapes have been recorded at the field station and are being analysed in the laboratory.

On replay, the tape speed is increased by a factor of one hundred to $1\frac{7}{8}$" per second so that the information (now in the range 0.5 to 10 Hz) appears as frequency modulation of a 1 kHz carrier. The micropulsation signals are obtained by frequency demodulating this audio tone via a monostable multivibrator and integrating the output pulses using a suitable R-C section.

Two factors have been observed to degrade the quality of the signal obtained after demodulation, relative to chart records made in the field at the same time as the magnetic tapes were recorded. Firstly, unseen movement of the magnetic tape on recording or replay (e.g. stretching of the tape, or irregular capstan rotation) has the effect of extending or compressing the length of a cycle on tape i.e. it causes an undesired frequency modulation of the carriers. This undesired signal, commonly called "wow", occurs simultaneously on all tracks in the same form and if not compensated for will lead to correlations between components even when no such correlations exist between the original micropulsation components. (See chapter 6 - "Magnetic Tape Instrumentation" G.L. Davies, McGraw-Hill, 1961). Figure 1.1 illustrates this effect in the case of recorded test sine waves.

Secondly, as the audio tone is demodulated using a monostable multivibrator, cycle by cycle reproduction of the recorded wave-form is necessary to obtain triggering pulses. On replay of the magnetic tape, however, this condition is not always satisfied. Irregularities in the structure of the tape, non-uniform contact with the tape head, etc. cause fluctuations in the amplitude of the reproduced signal, ranging from minor fadings to a complete dropout of signal for a number of cycles.

The basic demodulation system which has been developed to endeavour to overcome these defects is shown in the block diagram in Figure 1.3. The signal from the tape is amplified until it is of the order of a few volts. This signal is then compared with the output of a multivibrator and any phase difference is detected; this generates a D.C. voltage which is fed back to control the frequency of the multivibrator. In this way the multivibrator is phase-locked to the incoming signal. When there is a dropout of the incoming signal, the multivibrator will tend towards its free-running frequency, but because of the filtering of the feedback control voltage it will be held for a time at approximately the same frequency as the incoming signal before the dropout. As the dropout may last at most only ten cycles this means that negligible distortion results. If the multivibrator were simply triggered to synchronise with the incoming frequency this would mean its free running frequency would have to be lower than that of the incoming signal, and when a dropout occurred the multivibrator would revert immediately to its free running frequency, thus introducing a distortion of the demodulated wave which would always be in the one direction.

The phase-locked oscillator gives a constant amplitude output to generate triggering pulses for the multivibrator and thus effectively compensates for any dropouts that may have occurred. A valve multivibrator has been used so that the resultant demodulated wave is of the order of ten volts, which is the input level required by the Analog-to-Digital Converter. If a transistor system had been used this would have necessitated a subsequent amplifier stage to obtain the required output.

"Wow" compensation

All four tape tracks are demodulated in a similar way. The signal tracks are next passed through cathode follower stages whilst the "wow" track is phase inverted and then resistively added to each of the signal channels. This effectively subtracts the undesired wow from the signal leaving only the required micropulsation component. The D.C. level of the output is then set depending on the form of output required: for chart 0V ±5V for F.S.D., and for A/D conversion -5V ±5V for F.S.D. Detailed circuitry is given in Figures 1.4 - 1.10, whilst Figures 1.2, 1.13, 1.14 are examples of charted signal which have been reconstructed.

The above system has also been used to reconstruct other F-M tapes used to record earth currents from spaced stations. These tapes were recorded at 15/64 inch per second using 2 carriers of 270 Hz and 2 of 400 Hz. A wow correction carrier of 300 Hz was also recorded, mixed with one of the 400 Hz signals. On replay a filtering system (Figures 1.11, 1.12) was necessary to separate these mixed signals, but except for the differing frequencies resulting from a speed-up factor of eight (viz. 2160 and 3200 Hz for signals and 2400 Hz for wow) the remainder of the system is very similar to the above. Figure 1.15 is an example of components of earth currents from two stations approximately 65 kilometres apart.

Sample-Hold Circuit

Since the tape speed-up on replay results in signal frequencies up to 10 Hz, sequential digitization in the six-channel Analog-Digital Converter at the fastest punch rate would give a phase delay of about one cycle between channels one and six. It is thus obvious that for accurate comparisons of records a holding sampler is necessary; this ensures that all channels are sampled at the same instant in time.

In the circuit developed (Figure 1.16) a capacitor C is charged up to the input voltage; this voltage is then read off when required. At the fastest punching rate available the channel multiplexer remains on each channel for a period of 20 milliseconds. The final digitizing process and punching takes place during the last 4.5 ms of this period, thus leaving a time interval of 15.5 ms for sampling. In the circuit constructed, signal erasure and resampling occupies 13 ms of this time.

In order to obtain maximum information from less than 6 channels, a multipole switch enables two channels to be sampled three timer per cycle of the multiplexer, or three channels twice per cycle. This switch supplies the correct sequence of sampling trigger pulses as well as switching the input signals to the appropriate multiplexed channels. A sample time chart is shown in Figure 1.17.

Trigger pulses for the sampling circuit are taken from channels 1, 3, 4, 5 in the multiplexer. For digitizing more than three channels of information the trigger pulse is used from channel 1, i.e., the signal is sampled at the commencement of each multiplexer cycle of operation. For three-channel operation sampling is effected at the start of channels 1 and 4, while for two-channel operation sampling occurs at channels 1, 3, 5.

After inversion, the leading edge of the trigger pulse fires a monostable multivibrator, giving a pulse of length 3 ms used to discharge the storage capacitor through a transistor. The trailing edge of this pulse is also used to trigger a second monostable, the output of which is a pulse of length 4 ms. This closes the magnetic switch and allows the storage capacitor to charge up to the input voltage. Because of the long time constant of the relay coil, the charging process continues for about 7 ms (i.e. about 8 time constants of the charging network).

Voltage readout from the capacitor is accomplished by means of a field-effect transistor. Loss of voltage can occur through capacitor leakage, conductance through a back-biassed diode, and leakage through the field-effect transistor. The overall leakage resistance is the parallel combination of these three. Using a high quality low-leakage diode and a standard polyester capacitor, signals can be held without loss for periods up to 10 seconds, thus indicating a total leakage resistance of the order of 10 MΩ. If necessary, this could be improved even further by the use of a better quality capacitor (e.g. Mylar) and by the use of a MOS field-effect transistor rather than the junction gate type used here.

A disadvantage of the basic circuit is the presence of D.C. offset at the output, which arises from the non-cancellation of voltage drops in the charging transistor and diode (both silicon types). This offset was effectively removed by providing a reverse series voltage at the output. The system has an overall gain of 0.95 and the transfer characteristic is linear to better than 1%.

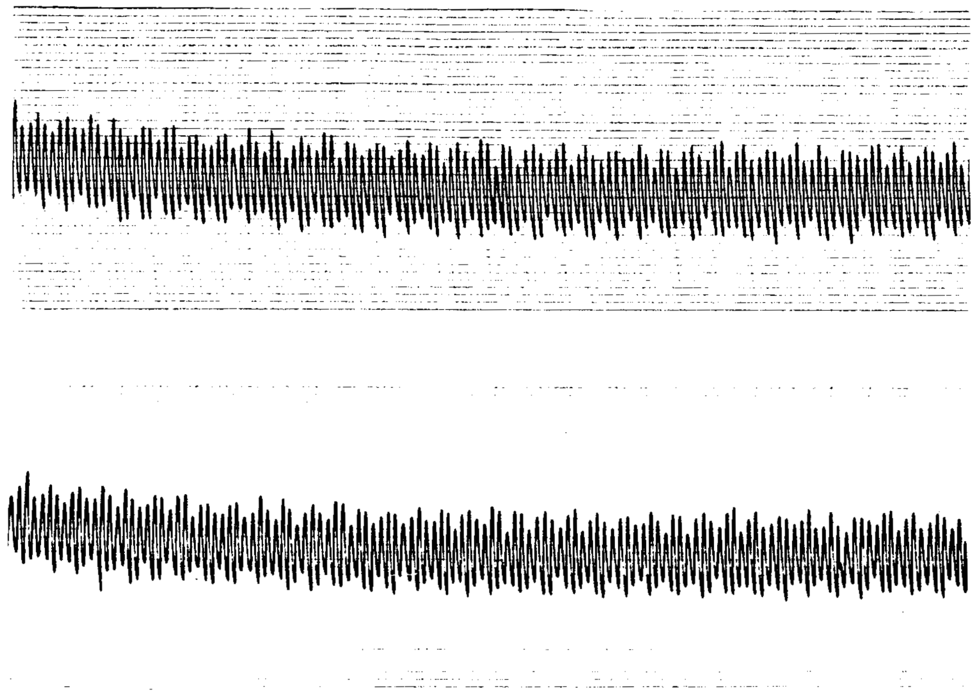


FIG. 1.1. RECONSTRUCTED TEST SINE WAVES
SHOWING EFFECT OF "WOW".

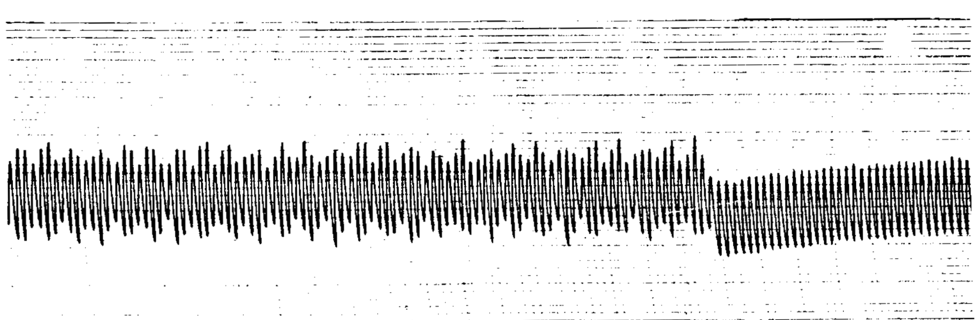


FIG. 1.2. RECONSTRUCTED TEST SINE WAVE
WITHOUT AND THEN WITH "WOW" COMPENSATION.

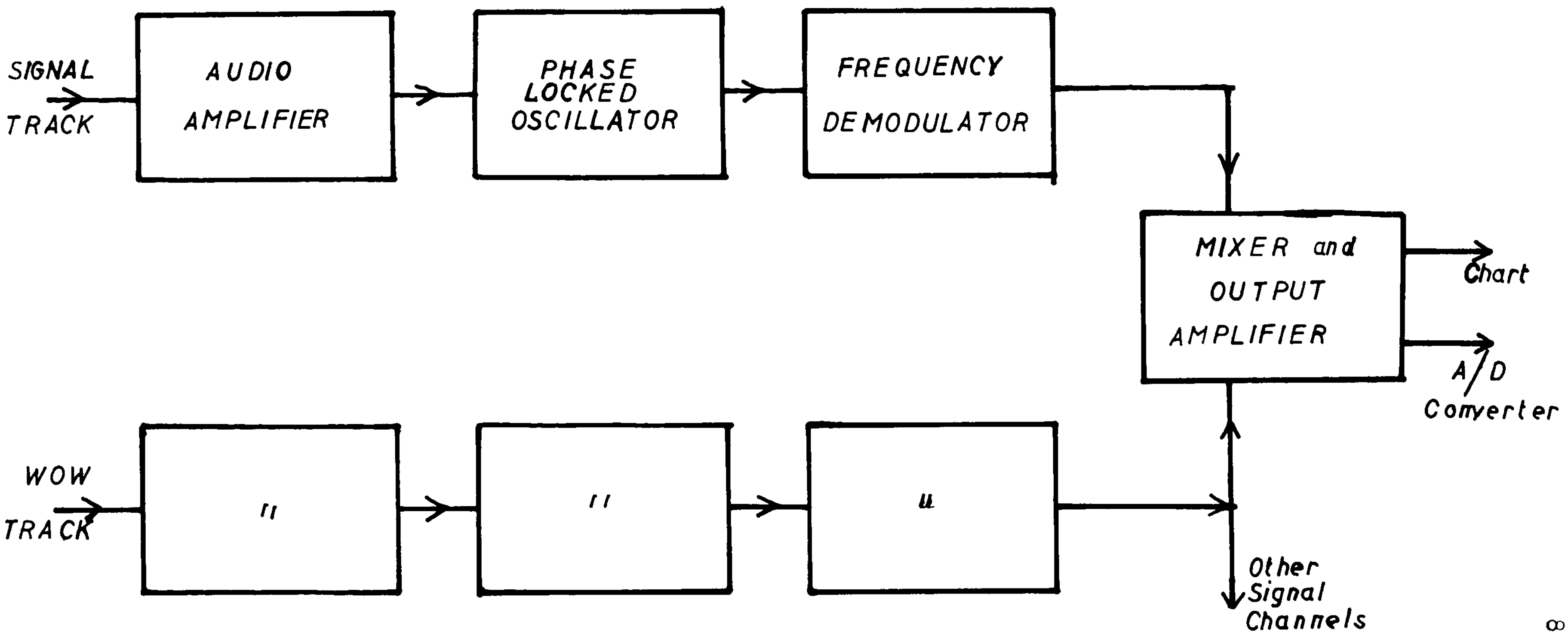


FIG1-3 BLOCK DIAGRAM – ANALOGUE SIGNAL RECONSTRUCTION

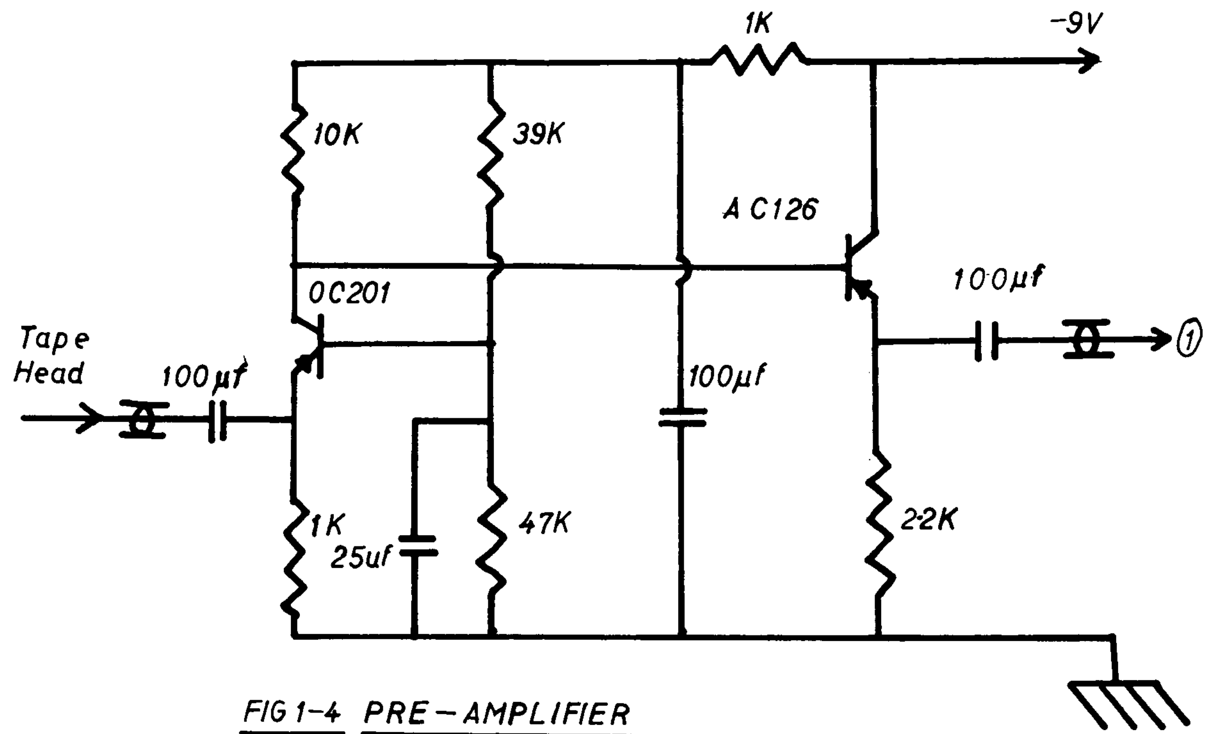


FIG 1-4 PRE-AMPLIFIER

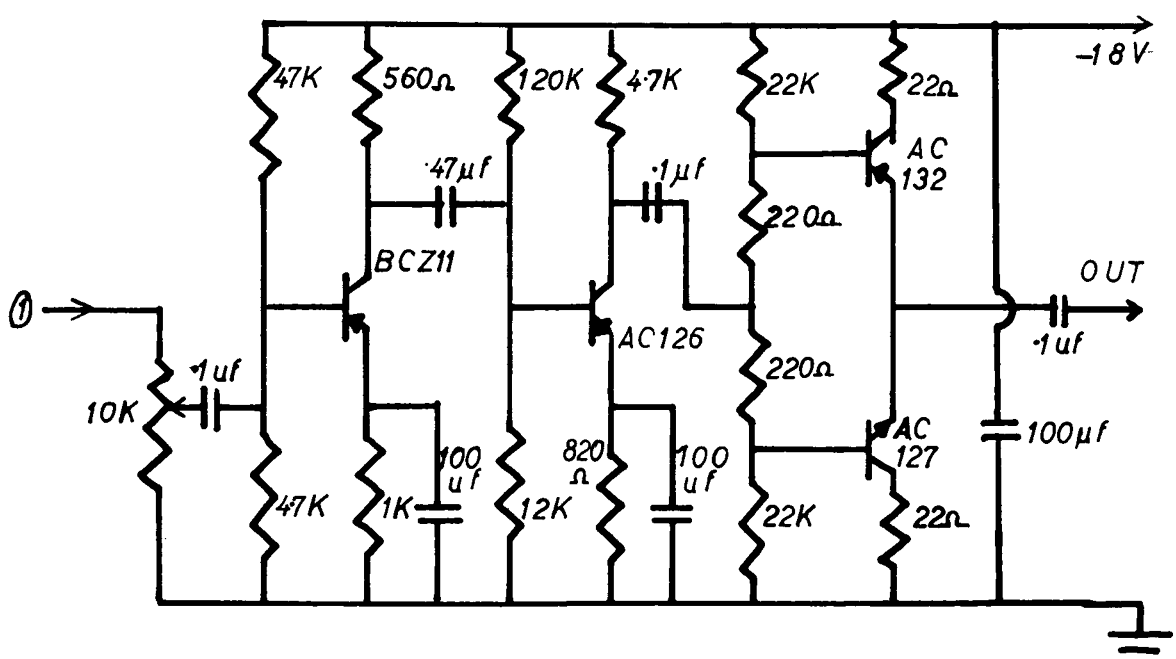


FIG 1-5 AUDIO AMPLIFIER

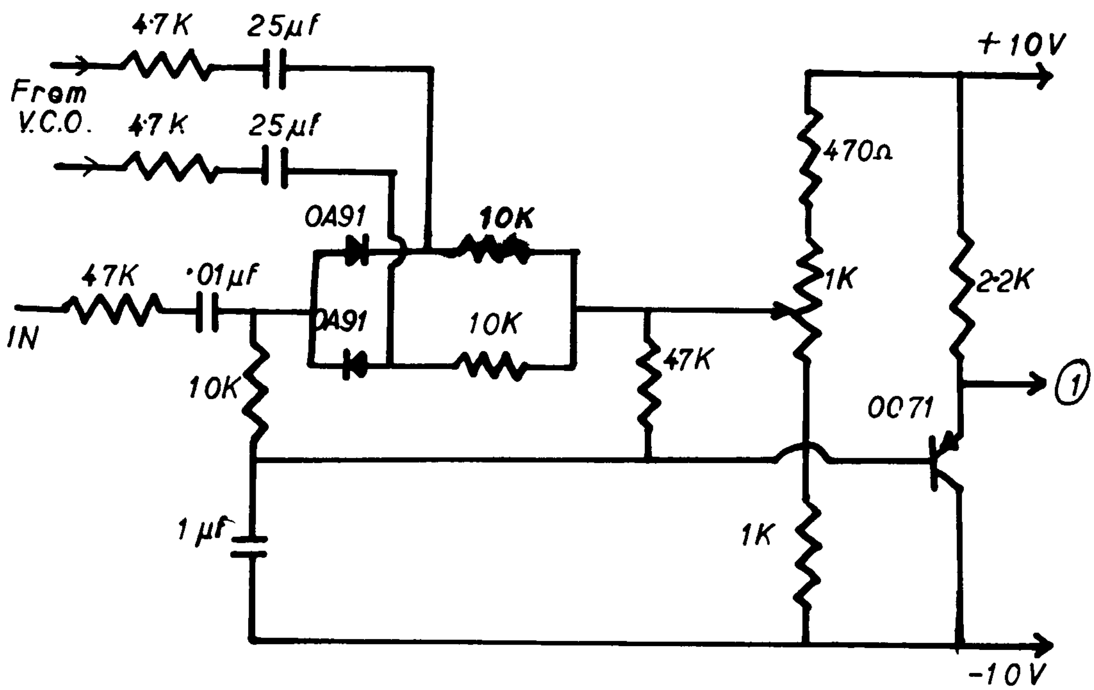


FIG 1–6 PHASE SENSITIVE DETECTOR

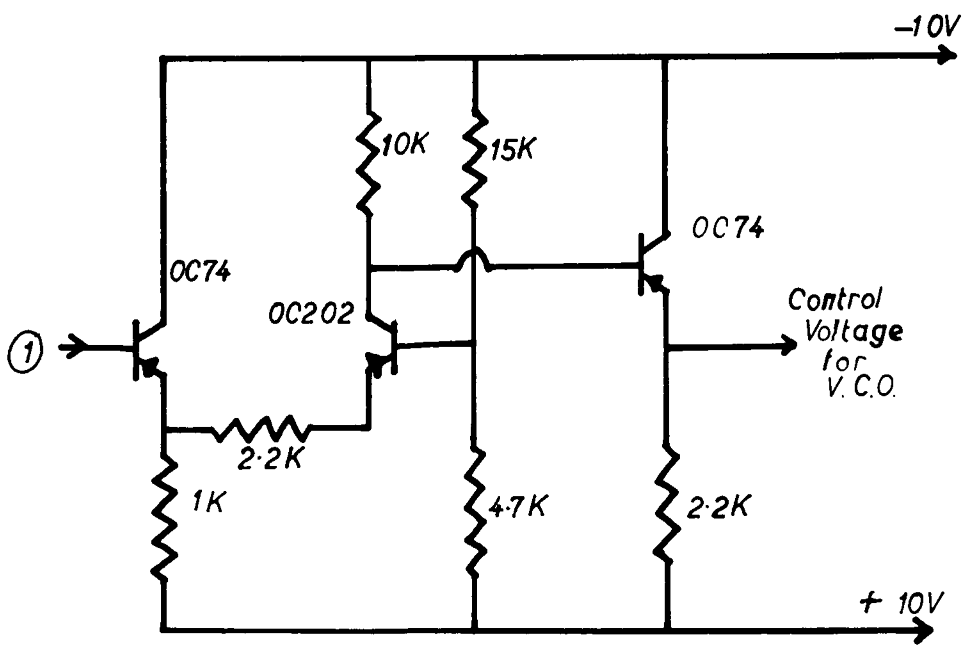


FIG 1-7 ERROR SIGNAL AMPLIFIER

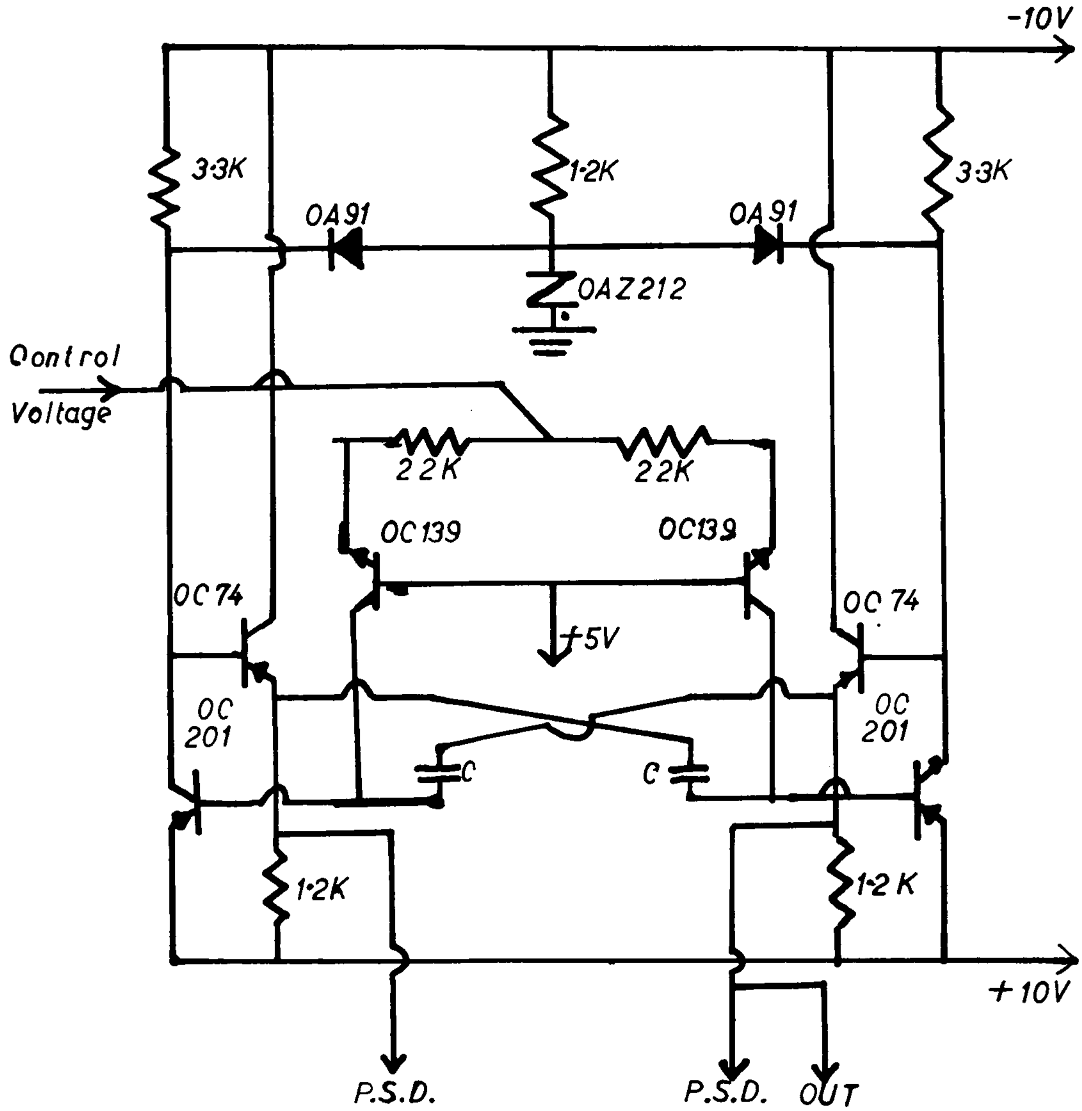


FIG1-8 VOLTAGE CONTROLLED OSCILLATOR

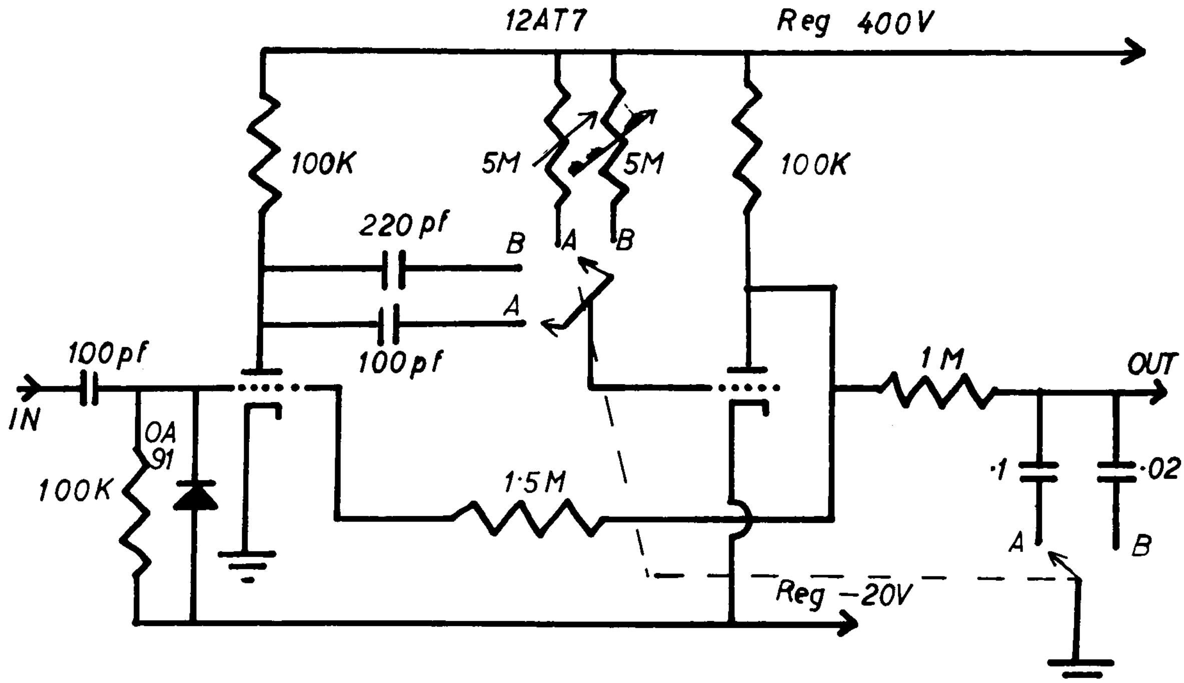


FIG 1-9 FREQUENCY DEMODULATOR

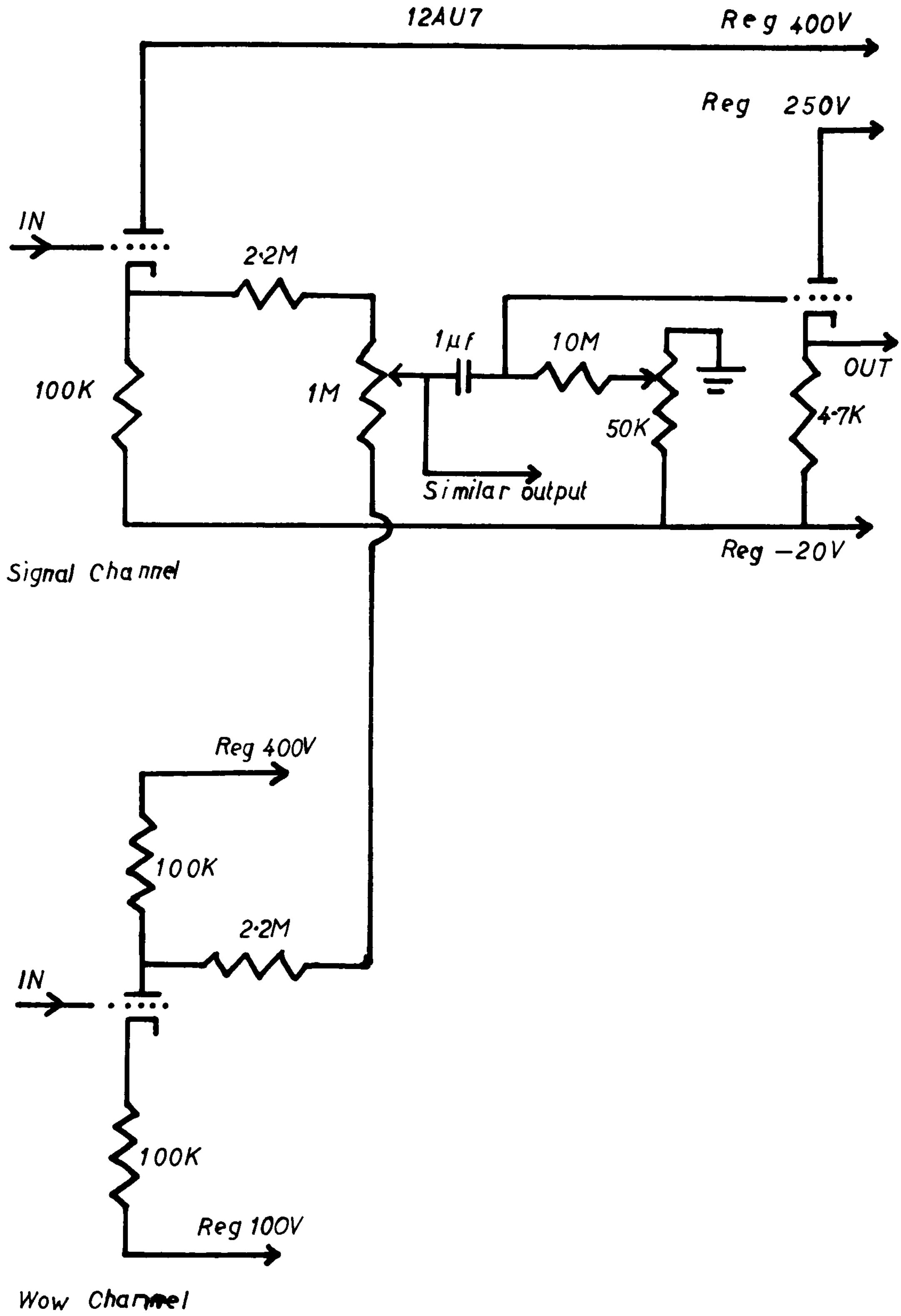


FIG 1–10 WOW COMPENSATION SYSTEM

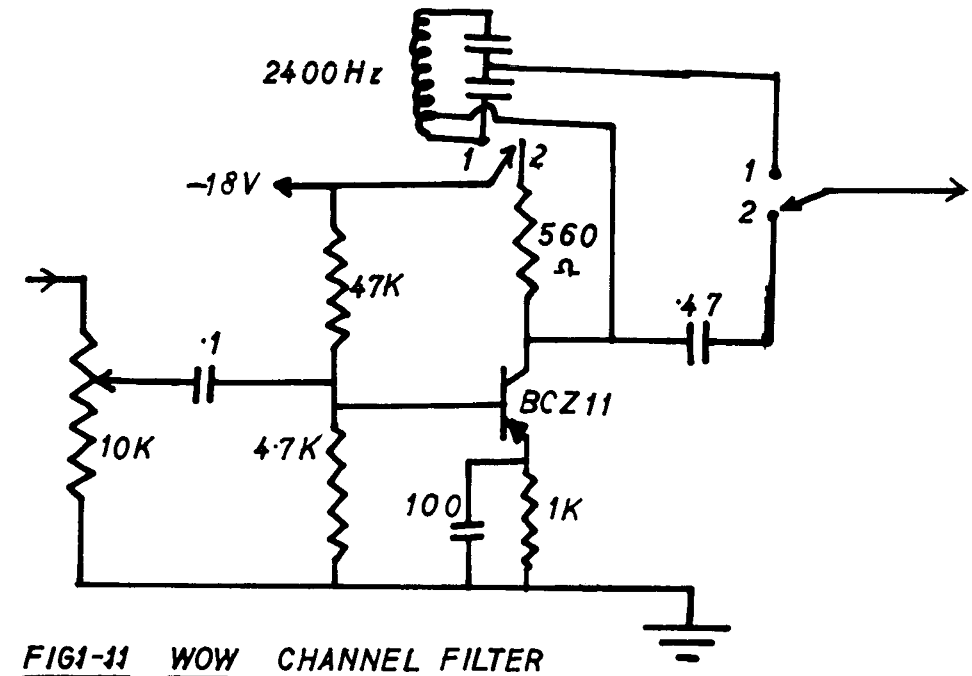


FIG1-11 WOW CHANNEL FILTER

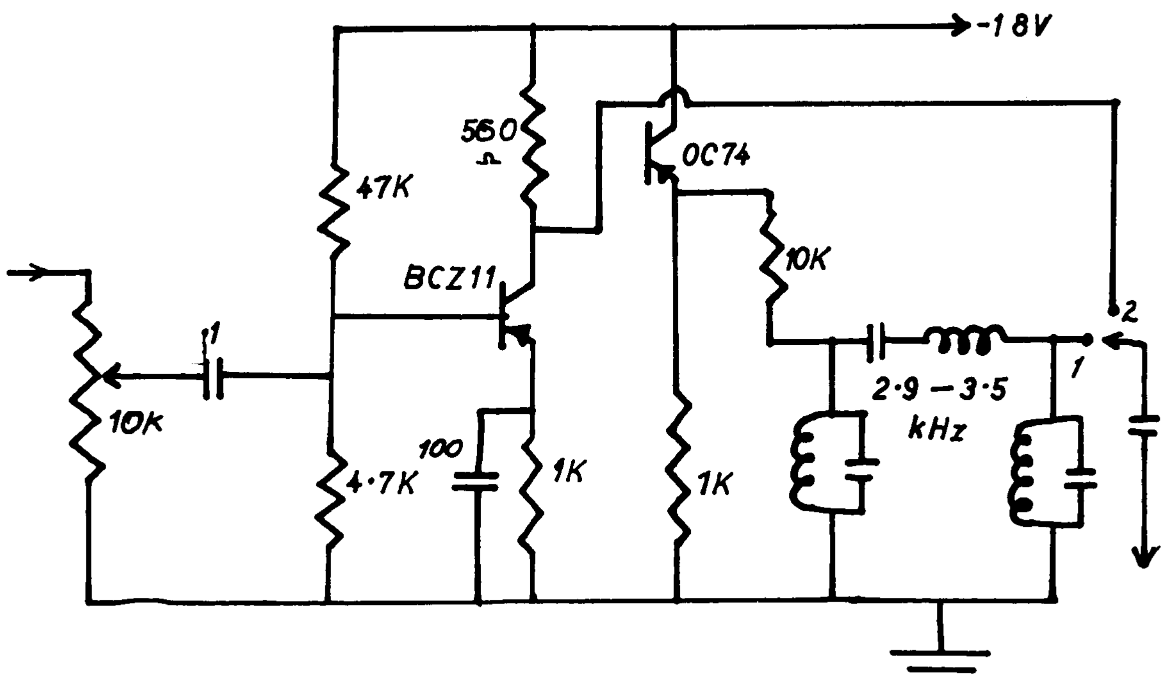


FIG 1-12 SIGNAL CHANNEL FILTER

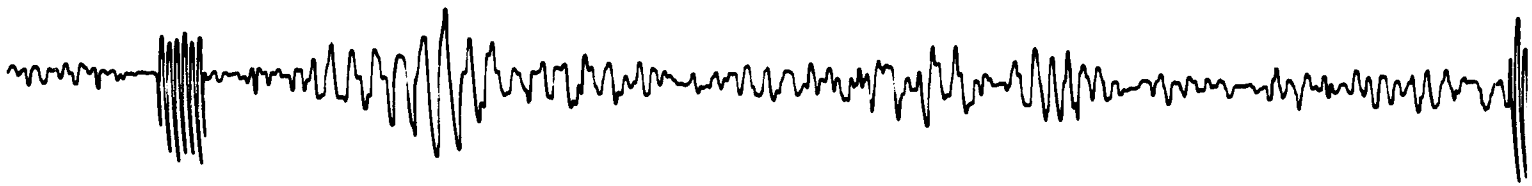


Fig. 1.13. H_{E-W} RECORDED IN FIELD AT ESK 0645 TO 0800, MAY 1ST, 1966.

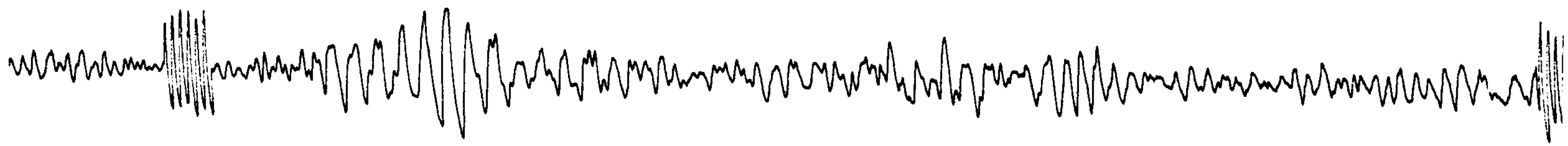


Fig. 1.14 SAME RECORD AS ABOVE RECONSTITUTED IN THE LABORATORY.

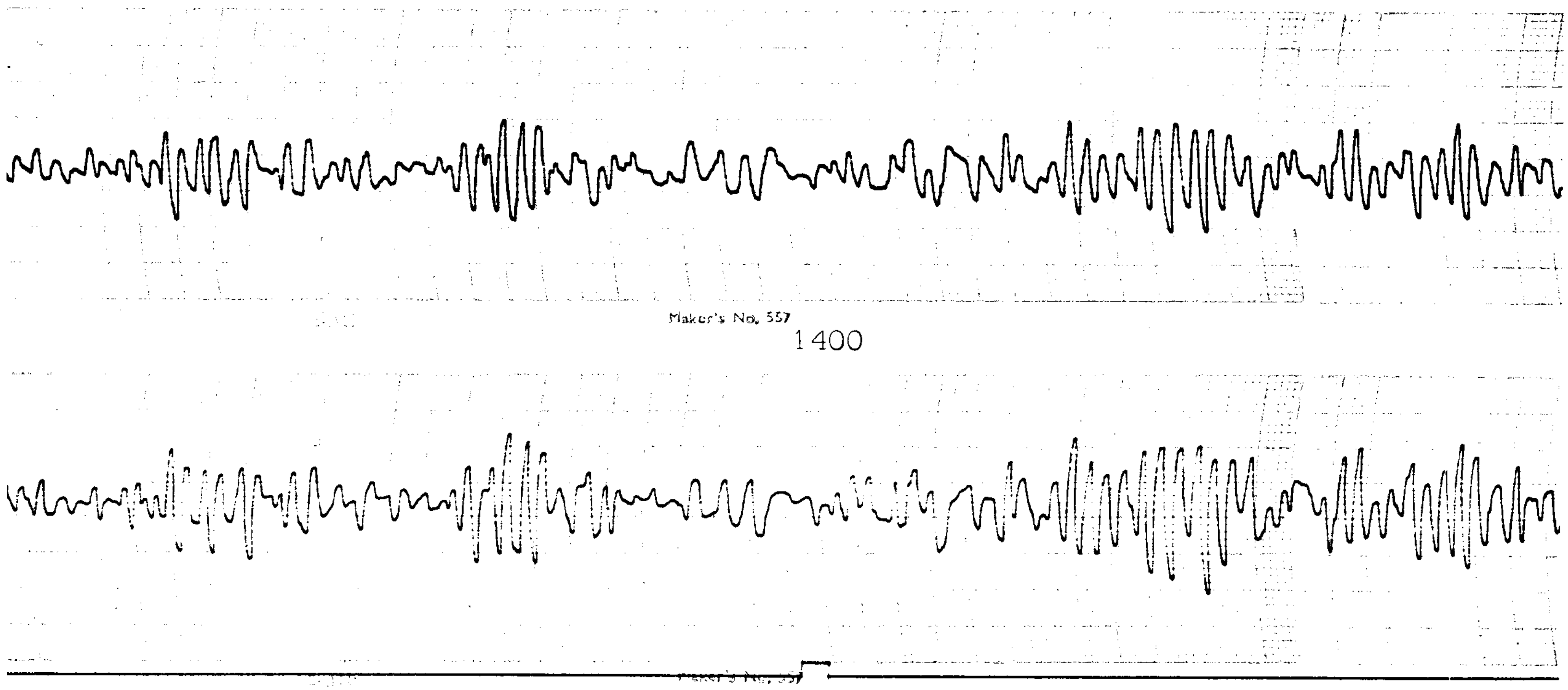


Fig. 1.15. N-S COMPONENTS OF TELLURIC CURRENTS ON OCTOBER 15, 1965. UPPER TRACK WELLCAMP, LOWER TRACK MILLMERRAN. CHART SPEED 18 cms PER HOUR.

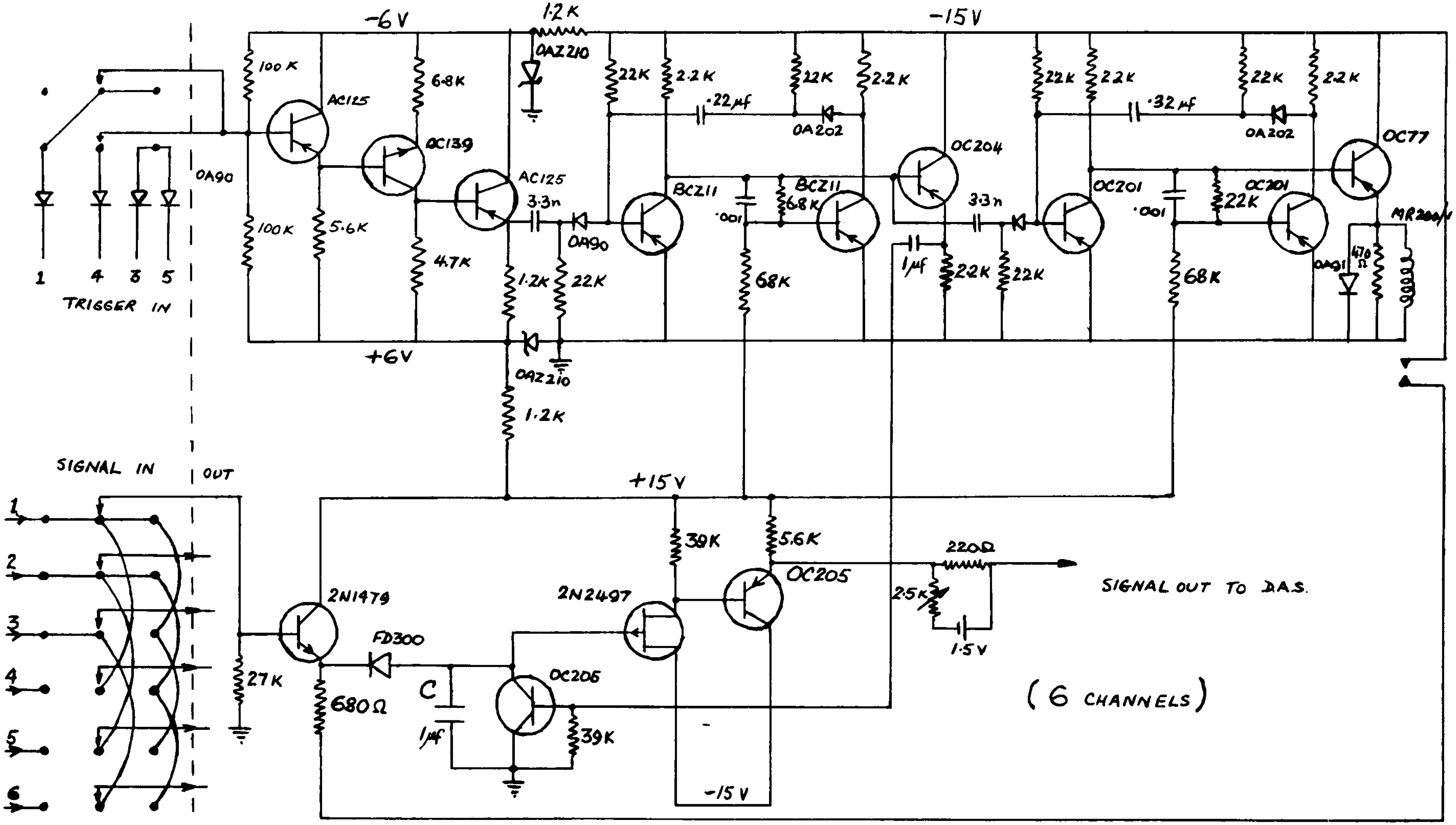


FIG. 1.16. SAMPLE-HOLD CIRCUIT.

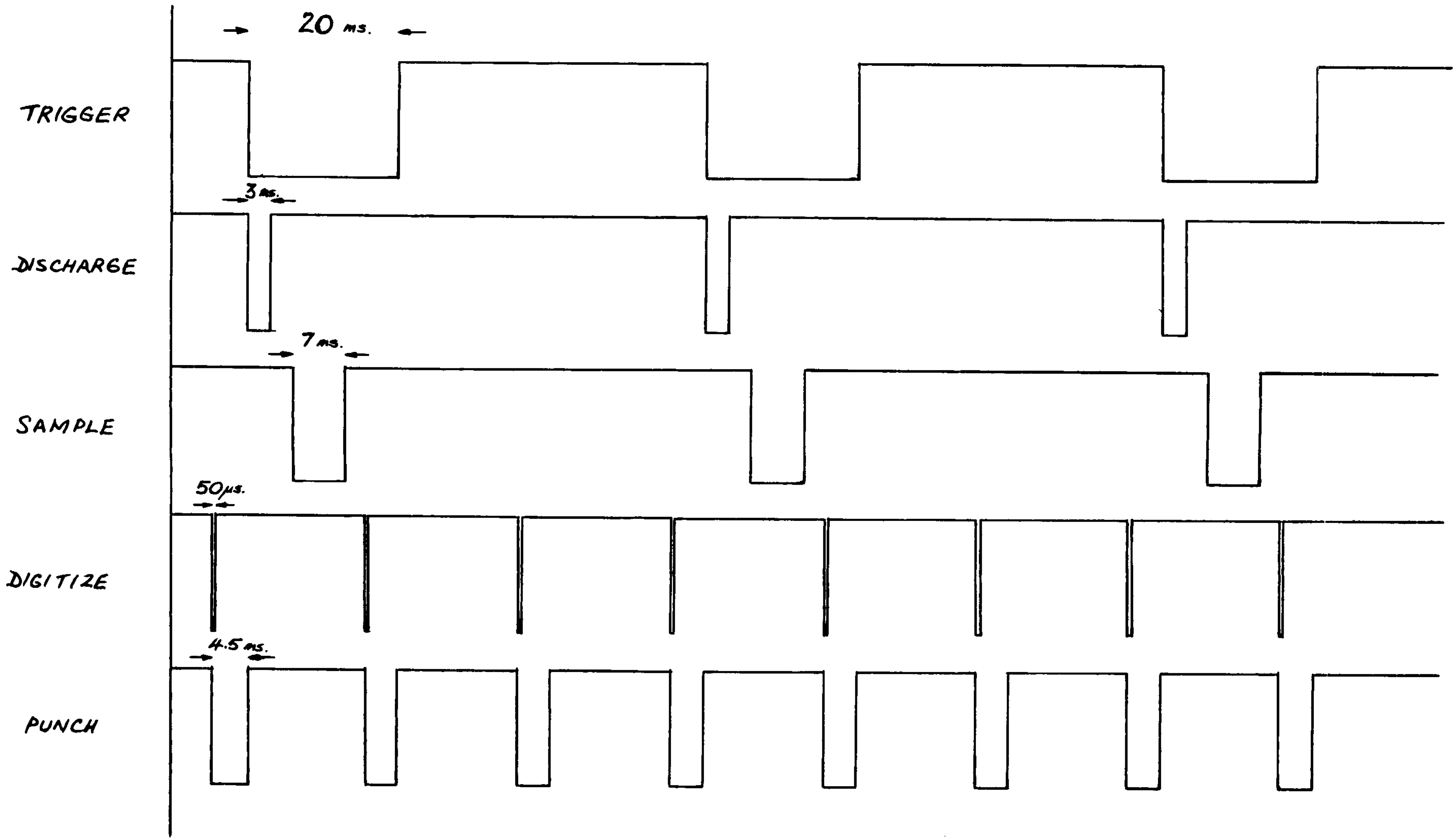


FIG. 1.17. TIME-CHART FOR 3-CHANNEL OPERATION.
(PUNCH RATE 50 p.p.s.)

2. OUTPUT OF DIGITIZED DATA FOR COMPUTATIONAL PURPOSES

I.M. Brazier

The Six Channel Data Acquisition System supplied under grant NGR-52-039-002 consists of a multiplexer, an Analog-to-Digital converter, a timer and a Tally perforator. The unit multiplexes six channels of data, digitizes and formats the data and transfers it to a punched paper tape.

Data in the form of 8 bit binary information is punched as single characters on eight channel paper tape. All six channels are punched sequentially at a rate which can be selected to be a sub-multiple of the synchronizing pulses used. The Data Acquisition System may be synchronized internally on line frequency or by suitable external pulses; the punching rate is determined by appropriate division of the synchronized pulse rate.

Reading of this particular format of eight channel paper tape for computational purposes has not been possible to date with the University of Queensland Computer Centre's GE 225 Computer. Consideration was given to the use of 6 or 7 bit binary information, but because of the loss of accuracy resulting from such a measure it was decided instead to perforate a second form of paper tape.

A Western Electric Company "Teletype" High Speed Tape Punch Set (BRPE 110) was readily available, together with a special Paper Tape Punching System which has 32 inputs which are punched sequentially four at a time, a hole being punched if the input voltage is zero or positive whilst no hole is punched if the input voltage is -4.2 volts. Hole numbers 2 to 5 of five channel paper tape are used for data recording whilst it is also possible with this system to punch manually any 5 bit character.

The Teletype punch is a synchronous unit having a magnetic pickup that produces synchronizing pulses at the rate of 110 per second, whilst the Tally Perforator Unit, Model 420, is asynchronous. A few minor modifications were necessary to use the Paper Tape Punching System in conjunction with the Six Channel Data Acquisition System.

Firstly, the pulses from the Teletype punch, which are used to synchronize the operation of the digitizer and the two punches, have been reshaped. Also, the punch rate switch in the Data Acquisition System has been rewired so that the synchronizing pulses fed back to the Paper Tape Punching System always occur at twice the rate of those which actually drive the Data Acquisition System and eight channel

Tally tape perforator. Secondly, the eight information signal levels for the Paper Tape Punching System, corresponding to the eight bits of binary information, were obtained from the logic levels which control the perforator solenoids in the Data Acquisition System. The 32 inputs of the Punching System were connected as indicated:-

Level corresponding to 128 bit	....	Inputs	(1,	9,	17,	25)	A
64 "	....	"	(2,	10,	18,	26)	B
32 "	....	"	(3,	11,	19,	27)	C
16 "	....	"	(4,	12,	20,	28)	D
8 "	....	"	(5,	13,	21,	29)	E
4 "	....	"	(6,	14,	22,	30)	F
2 "	....	"	(7,	15,	23,	31)	G
1 "	....	"	(8,	16,	24,	32)	H

Thirdly, the reset conditions of both systems were readjusted so that when activated the following sequence of events occurs.

Punch Synch. Pulse.	Data Acquisition System	Tape punching System
1st	Multiplexer goes to channel 1 and information digitized.	Inputs A-D i.e. 4 most significant bits of channel 1 information punched.
2nd	Multiplexer remains on channel 1 and 8 bit information punched by Tally perforator.	Inputs E-H i.e. 4 least significant bits of channel 1 information punched.
3rd	Multiplexer goes to channel 2 and information digitized.	Inputs A-D i.e. 4 most significant bits of channel 2 information punched.

Successive pulses cause the Teletype punch to punch the 4 most significant bits and then the 4 least significant pits of the information whilst alternate pulses cause the multiplexer to cycle through the six channels of information with the Tally perforator punching all 8 bits of the information at half the rate of the Teletype punch.

Although the digitizer will perform a digitization of the information for every synchronizing pulse from the Teletype punch (even though the actual punch rate is only a fraction of this rate) this will not introduce any errors as the information being digitized has been held constant by a sampling circuit, which acts as an analog memory, preceding the Data Acquisition System.

By manually punching using a hole in hole number 1 of the 5 channel paper tape, it is possible to put additional coded information on to the tape. This may be in the form of control data for computational purposes, or alternatively, information such as date or other identification may be added. As all eight hole positions are used for information on the eight channel paper tape from the Tally perforator it is not possible to include such extra coded data on these tapes.

3. STANDARDIZATION OF EQUIPMENT SENSITIVITY AND ROUTINE CALIBRATIONS

R.W.E. McNicol & R.S. Fitchew

In order to give a fully quantitative description of the micropulsation field at a given place and time, and to compare accurately the amplitudes of the various components at a single station or at separated stations, it is necessary that the recording equipment be so calibrated that its absolute sensitivity is known, and can be checked on a routine basis.

At Esk it has proved convenient to record all three magnetic components at the same sensitivity; thus a standard alternating magnetic field applied to each of the sensors produces identical signals in all three channels of each of the final data recording systems (chart, F.M. tape, and slow speed tapes).

As indicated in Section xiv of the 3rd Semi-Annual Report, the primary standard alternating magnetic field used in calibration is obtained by rotating at a constant known rate a magnet of accurately known moment, placed a measured distance from the pick-up coil. However, this method is inconvenient for routine calibration; for that purpose a secondary standard is used: an alternating current of known amplitude, and of the same frequency as the rotating magnet, is applied to the calibration coils on the mu-metal-cored magnetic sensors. This calibrating current is obtained from a standardizing oscillator, which will be described later.

The procedure for setting the standard calibrating current for each pick-up coil, and for adjusting the sensitivities of the recording systems, is essentially as follows:- the pick-up coil is placed in a specified test position for which the alternating field due to the rotating magnet has been calculated, and with the magnet rotating at 0.05 revolutions per sec, the peak-to-peak output voltage of the "Medistor" pre-amplifier connected to the pick-up coil is noted. The rotating magnet is then brought to rest, and the standardizing oscillator turned on, and a variable resistor (in the calibration connector panel) in series with the calibration coils is adjusted to give a current through the calibration coils which produces the same output voltage from the "Medistor" pre-amplifier as the rotating magnet did. This standard calibrating current (for this particular magnetic sensor) is noted and used in all subsequent calibrations. The gain control of the voltage amplifier and of the appropriate channel of all the tape recording systems is adjusted to give the required level of the recorded signal on chart and all magnetic tapes.

The same procedure is repeated for each of the other two magnetic components, the pick-up coil being placed in the same test position in each case. Tests have shown that the sensitivity of the pick-up coils does not alter appreciably when they are moved back to their normal recording positions. Subsequent calibrations can then be done by merely producing again the standard calibrating current appropriate to each magnetic sensor in its calibration coils, without reference to the rotating magnet. In practice this is done automatically for a few minutes at the beginning of each hour, and for ten minutes each midnight, so that any variations in equipment sensitivity can be seen by inspection of the chart or replay and demodulation of the F.M. tape. In addition, a thorough calibration, in which the gain and any D.C. offset of each individual unit in the recording system are also checked, is made during the routine weekly visits to the field station.

Because of its use as a secondary standard for calibration purposes, it is important that the standardizing oscillator should produce a sinusoidal wave form of low distortion, and of constant amplitude and frequency. Consequently a better quality oscillator has been designed to replace the calibration oscillator described in section xiii of the 3rd Semi-Annual Report.

The circuit of the new standardizing oscillator is shown in Fig. 3.1. It is essentially a phase-retard RC oscillator in which amplitude stabilization is achieved by using amplifier saturation, as described by L. Nelson-Jones (1965). The phase-retard network, shown in Fig. 3.2, has switched resistors and capacitors, thereby providing a choice of six frequencies. The oscillation frequency is given by $f = \frac{\sqrt{6}}{2\pi RC}$, and the values of R and C used were adjusted until the frequencies were closely equal to 50, 100, 200, 500, 1,000, 2,000 mHz respectively.

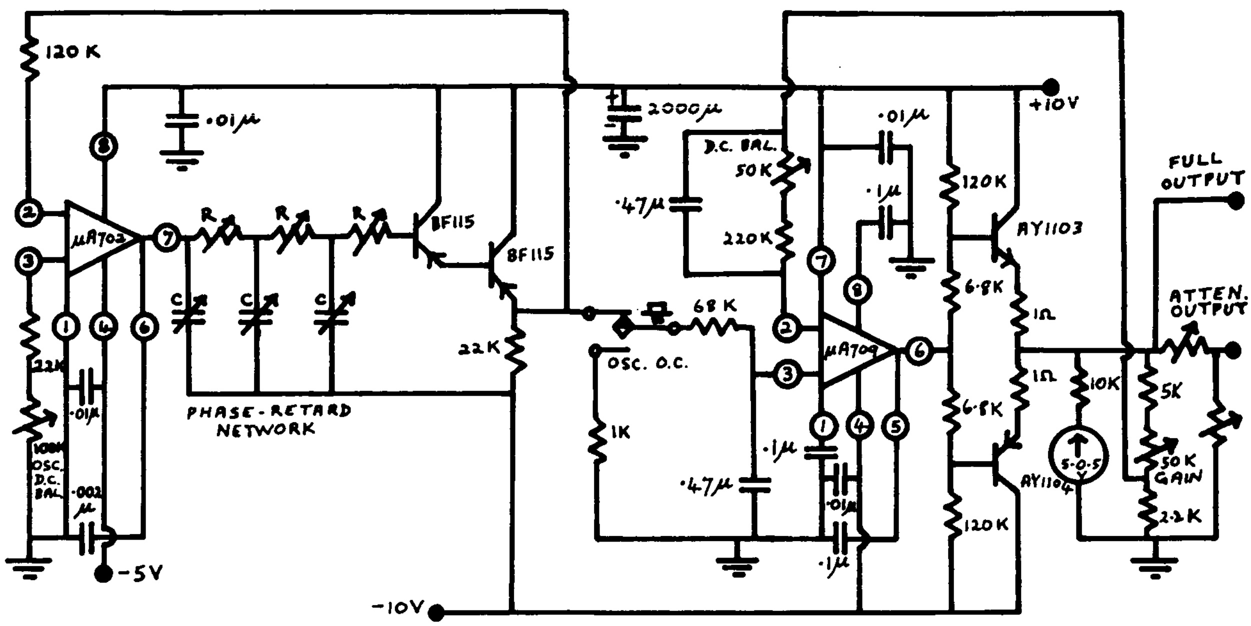
The "Fairchild" µA702 operational amplifier used in the oscillator circuit has sufficient gain (an open loop gain of 2,300) to ensure that it is saturated to the extent that its output is a square wave, of amplitude 9V p-p, this amplitude being dependent almost entirely on the value of the (stabilized) supply voltages. It is this feature which ensures the amplitude stability of the oscillator. The output of the phase-retard network (which is also fed back to the input of the µA702) is then a sine wave of amplitude $\frac{1}{23}$ that of the square wave, i.e. about 400 mV p-p containing 2% third harmonic distortion, 0.3% fifth harmonic distortion, and negligible amounts of the higher odd harmonics.

For ideal operation, the output of the phase-retard network must be presented with an input impedance much greater than the fairly large value of the resistors R in the phase-retard network. This is achieved by the use of a two-stage emitter follower, as seen in Fig. 3.1. The output of the emitter follower is then amplified to the required level by a Fairchild μA709 operational amplifier, followed by a complementary-pair power output stage to provide a low output impedance and reasonably large output currents if required. The gain of the μA709, and hence the amplitude of the full output signal, is made continuously variable by means of a variable resistor which controls the amount of negative feedback. The maximum amplitude available is 5 V peak.

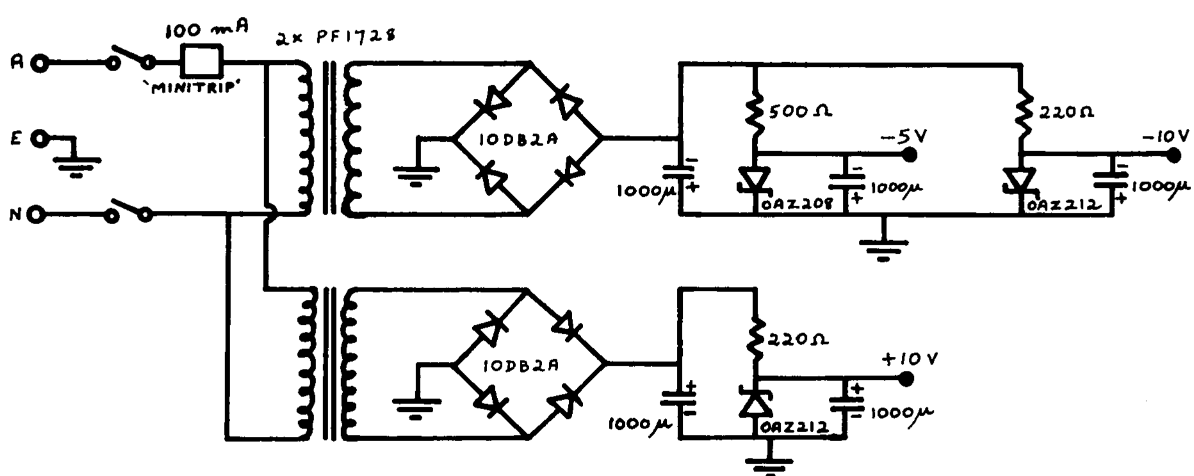
In addition to the full output, an attenuated output is available from which decimal sub-multiples down to 10^{-6} of the full output amplitude are available. The attenuator, which presents a constant load of 1KΩ to the output stage, is shown in Fig. 3.3.

Reference

Nelson-Jones, L. (1965) "Amplitude-stabilized RC oscillator", Wireless World Vol. 71, Nov. 1965, pp. 536 - 539.



OSCILLATOR AND AMPLIFIER



POWER SUPPLIES

Fig. 3.1 CIRCUIT DIAGRAM OF STANDARDIZING OSCILLATOR

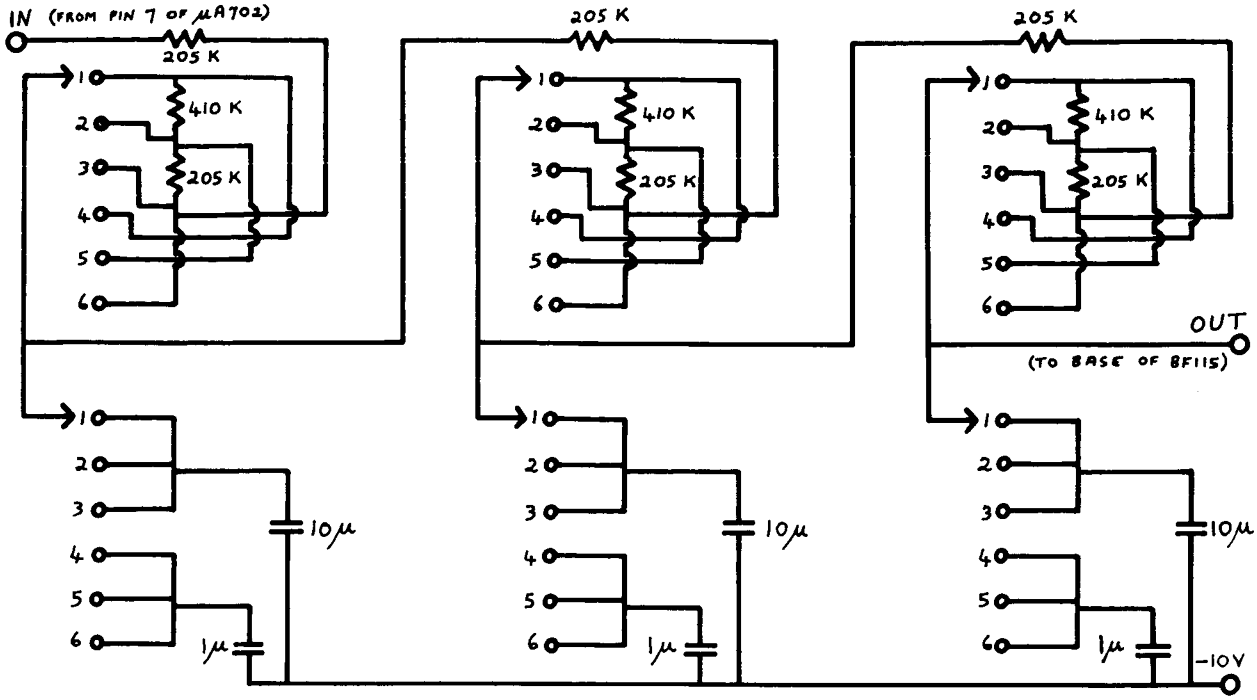


Fig. 3.2 SWITCHED PHASE-RETARD NETWORK OF STANDARDIZING OSCILLATOR.

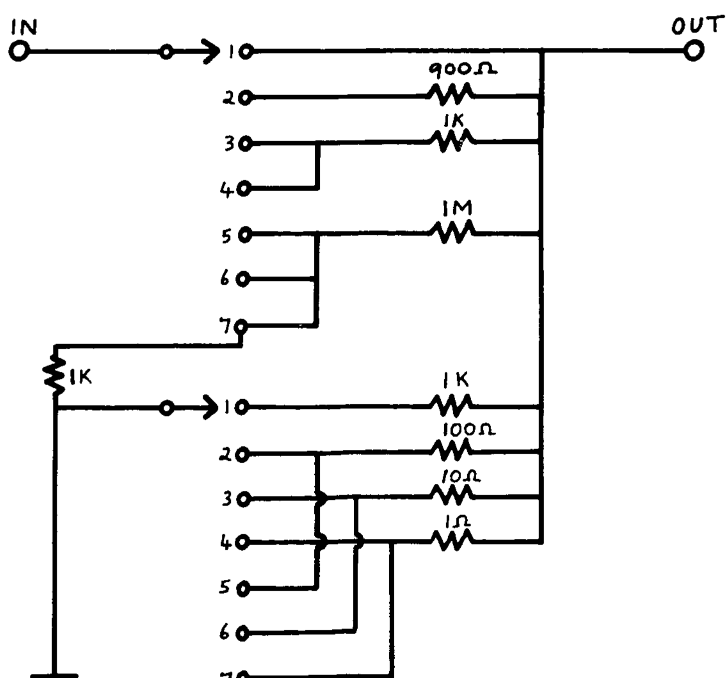


Fig. 3.3 OUTPUT ATTENUATOR OF STANDARDIZING OSCILLATOR.

4. A TIMING SYSTEM FOR USE WITH SLOW-SPEED F.M. TAPE RECORDING.

J.S. Mainstone

Introduction.

The unit described below has been designed, and the idea tested in basic form, but the final construction has not as yet been carried out.

In the course of experiments to determine the characteristics of micropulsations at widely separated stations in Australia it is proposed to make use of a series of slow-speed F.M. tape recorders of the type in use at the Esk base station. The F.M. method of recording provides a simple method of accurately storing analog data for subsequent digitization. For many purposes, such as phase comparison measurements, it is necessary to have accurate timing information available on replay. It is unlikely that a complete log of equipment breakdowns, power failures etc. would be forthcoming from remote sites (visited perhaps once a week). A simple time-mark system, i.e. a recognizable mark every quarter hour, requiring counting from a zero time in order to establish the particular quarter hour, is therefore not satisfactory.

Thus the purpose of the timing system described below is three-fold:

(a) to provide coded time marks each quarter hour on the slow-speed F.M. tapes,

(b) to determine time unambigously when replaying tapes from numbers of different remote stations,

(c) to allow programming of the Analog-to-Digital converter so that digitization of a sample may commence precisely at the beginning of any predetermined quarter-hour interval during the day.

F.M. Tape Recording System

For slow-speed F.M. recording of micropulsation signals, a 4 x $\frac{1}{4}$ track Marriott head stack (for $\frac{1}{4}$" tape) is mounted on a specially constructed deck which runs at $67\frac{1}{2}$"/hr. This tape-advance speed is chosen to be $\frac{1}{100}$ of the standard tape replay speed $1\frac{7}{8}$"/sec which is employed when analysing the F.M. micropulsation data tapes. There are 3 signal channels, each using a carrier frequency of 10 Hz and a frequency deviation of $\pm$ 10%. The fourth channel is used for wow correction, an unmodulated 10 Hz signal being used as the reference.

Because of the slow tape speed, voice announcements cannot be superimposed; instead the timing information is recorded on the same track as the wow-correction signal in the form of a series of pulses, each of duration 2 secs and a "carrier" frequency of 4Hz. On replay it is relatively easy to separate the 10 Hz (with a slight wow-induced modulation) from the 4 Hz timing pulses; actually since such separation occurs at a speed-up of 100 times, the frequencies are $\sim$ 1 kHz and 400 Hz respectively.

Timing Pulses to Indicate Each $\frac{1}{4}$ Hour

The timing tone (4 Hz) pulses, duration 2 seconds in real time, separated by 2 seconds, are coded for recording on the F.M. tape in the following manner:-

TIME	NO. OF PULSES
0015	1
0030	2
0045	3
0100	4
----	-
0200	8
----	-
----	-
1200	48
----	-
----	-
2345	95
0000	96

On replay the speeded-up pulses are fed to a digital read-out counting system which indicates time according to the above code, at least in the first instance, though it is obviously possible to provide a direct "time read-out" facility by decoding the pulses. The counting system must be re-set to zero before the next series of pulses arrives, thus making it possible to begin playing a tape at any point and to determine the time at which the signal was actually recorded.

The 4 Hz timing pulses are also required to initiate the operation of the Analog-to-Digital converter. If the particular combination of digits at the output of the replay counting system corresponding to a certain indicated time is to be used to pre-set the trigger for the converter, it follows that the whole train of pulses must have passed into the counter by this time. i.e. when coding the original tape recording, the last pulse of the train must always be the one corresponding to the actual instant of time desired. For example, as shown in Fig. 4.1, for 0030 two pulses are required, spaced by two seconds, the second pulse beginning at 0030; the pulses must therefore begin 4 seconds before 0030. Similarly at 0045 the pulses must start 8 seconds before 0045, and at 0100, 12 seconds before, etc.

In order to fulfil these conditions it is necessary that the timing sequence be started by a "clock" which gains 4 seconds each $\frac{1}{4}$ hour (900 seconds). This can be accomplished by driving two digital read-out counters from the one source of "seconds" impulses from a crystal clock (or perhaps from a mains-operated 1 rev/sec. motor, plus a cam and microswitch). The first counter (COUNTER 1) is arranged to reset after 899, the second (COUNTER 2) after 895. Each time COUNTER 2 reads 000 the timing sequence begins and when COUNTER 1 reads 002 the sequence ends. The two clocks must read 000 simultaneously at 0015, so that a daily re-set control has to be provided. Thus by the following midnight, for example, the sequence will begin 380 seconds before midnight, there being 96 pulses in all (95 of them before midnight) and 95 spaces of 2 seconds duration.

Assuming that the replay counting device responds very rapidly to the leading edges of the incoming pulses, the Analog-to-Digital converter will be triggered very nearly at the exact instant of the time required.

Method of Recording Timing Pulses

A block diagram of the generation and recording system for the timing pulses is given in Fig. 4.2.

The "seconds" output from a crystal clock feeds a 1 Hz square wave continuously to COUNTER 1, and through the COUNTER 2 INPUT GATE TO COUNTER 2. THE TIMING PULSE SEQUENCE GATE is operated by the appropriate commands from the two counters, applied through AND gates. As indicated in the diagram, the timing pulse varies in length from 2 seconds (at 0015) to 382 seconds (at midnight). The 1 Hz input is divided by 4 to give a 0.25 Hz square wave which controls the 4 Hz square waves, each 2 seconds long; the 4 Hz square wave is derived from the crystal clock and is therefore phase-locked to the 1 Hz input signal.

On combining the outputs of the TIMING PULSE SEQUENCE GATE and the 4 Hz PULSE GATE in the 4 Hz PULSE SEQUENCE GATE, a succession of from 1 to 96 carrier-frequency pulses of 2 seconds duration, spaced by 2 seconds, is obtained. After filtering, this series of pulses is recorded on the wow-correction track of the magnetic tape by a direct recording process in which the 10 Hz wow reference signal is used as bias for the 4 Hz signals. (With Marriott tape heads used, optimum replay occurs with 4 mA of 10 Hz and about 0.5 mA of 4 Hz, fed through suitable isolating resistances).

To avoid filtering complications on replay of the compound signal it is desirable to have as little side-band content as possible in the recorded timing pulses, but at the same time this must be consistent with the requirement of a fast rise time in the reproduced pulses in order to preserve timing accuracy. Now a series of carrier-frequency pulses of duration T and repetition rate $f_r (= \frac{1}{T_r})$ has Fourier Components given by the series,

$$e = \frac{ET}{T_r} \left\{ \cos 2\pi ft \right.$$

$$+ \frac{\sin \frac{\pi T}{T_r}}{\frac{\pi T}{T_r}} \cos 2\pi (f+f_r)t + \frac{\sin \frac{2\pi T}{T_r}}{\frac{2\pi T}{T_r}} \cos 2\pi (f+2f_r)t + \ldots\ldots$$

$$\left. + \frac{\sin \frac{\pi T}{T_r}}{\frac{\pi T}{T_r}} \cos 2\pi (f-f_r)t + \frac{\sin \frac{2\pi T}{T_r}}{\frac{2\pi T}{T_r}} \cos 2\pi (f-2f_r)t + \ldots\ldots \right\}$$

Where E is the amplitude and f the frequency of the carrier, assumed to be sinusoidal in form.

In the present case we have

$$T = 2 \text{ seconds}$$
$$T_r = 4 \text{ seconds}$$
$$f = 4 \text{ Hz}$$
$$f_r = 0.25 \text{ Hz}$$

so that $\frac{T}{T_r} = \frac{1}{2}$, and hence all terms with coefficients

$\dfrac{\sin \frac{n\pi T}{T_r}}{\frac{n\pi T}{T_r}}$, where n is even, must vanish. It follows that the first few side-bands which have non-zero amplitudes are as follows:-

Side-band frequency	Amplitude relative to 4 Hz carrier
4.25 Hz, 3.75 Hz	+ 0.65
4.75 Hz, 3.25 Hz	- 0.21
5.25 Hz, 2.75 Hz	+ 0.13
5.75 Hz, 2.25 Hz	- 0.09

It is therefore possible to pass the carrier-frequency pulses through a bandpass filter to eliminate all frequencies above, say, 6 Hz and yet preserve quite good timing accuracy.

The other units shown in Fig. 4.2 provide for the re-setting of the counting system to zero at 0015 each day. At the instant of midnight, COUNTER 1 reads 000 whilst COUNTER 2 reads 380. This particular combination of digits (in binary form) operates an AND gate which triggers the BISTABLE SWITCH, thereby closing the COUNTER GATE through which the 1 Hz pulses are fed to COUNTER 2; actually a small DELAY is interposed between the BISTABLE SWITCH and COUNTER 2. With the gate open, COUNTER 2 then remains at 380 until COUNTER 1 next reads 000 i.e. at the instant of 0015. At this instant the AND gate operates again and hence triggers the BISTABLE SWITCH, thereby resetting COUNTER 2 to 000. After a small delay the COUNTER GATE is opened, so that the succeeding 1 Hz impulses pass into COUNTER 2.

Recovery of Timing Pulses from the Magnetic Tape

On replay at 1⅞"/sec the wow reference signal becomes a nominal 1,000 Hz and the carrier frequency of the timing pulses, 400 Hz. The mixed signal is amplified and the two components separated by passing through rejection filters as shown in Fig. 4.3. The 400 Hz pulses are then amplified, detected and re-shaped in the PULSE SHAPING UNIT, the output of which is then suitable for driving the MONOSTABLE PULSE GENERATOR. The constant amplitude, constant length output of this monostable generator provides the input to the TIME INDICATOR COUNTER, which must be reset before the next train of pulses begins. The longest train of pulses, 96 in all, occurs at midnight; after speed-up by a factor of 100, these occupy 3.82 seconds, beginning 3.80 seconds before the instant representing midnight. Thus the reset pulse must not occur later than about 5 seconds after the last pulse in the train has registered in the counter.

The leading edge of the first pulse in the timing sequence triggers the RESET MONOSTABLE which then remains on for an interval of 8 seconds, at the end of which the RESET PULSE GENERATOR operates, thus resetting the TIME INDICATOR COUNTER to zero. It follows that when the indicated time is 0015 the TIME INDICATOR COUNTER holds this setting for about 8 seconds whereas at the other extreme, at midnight, the count is held for only about 4 seconds.

The Analog-to-Digital converter may be programmed to begin operation at any pre-selected time by feeding the appropriate outputs from the counter through an AND gate as a command to the converter.

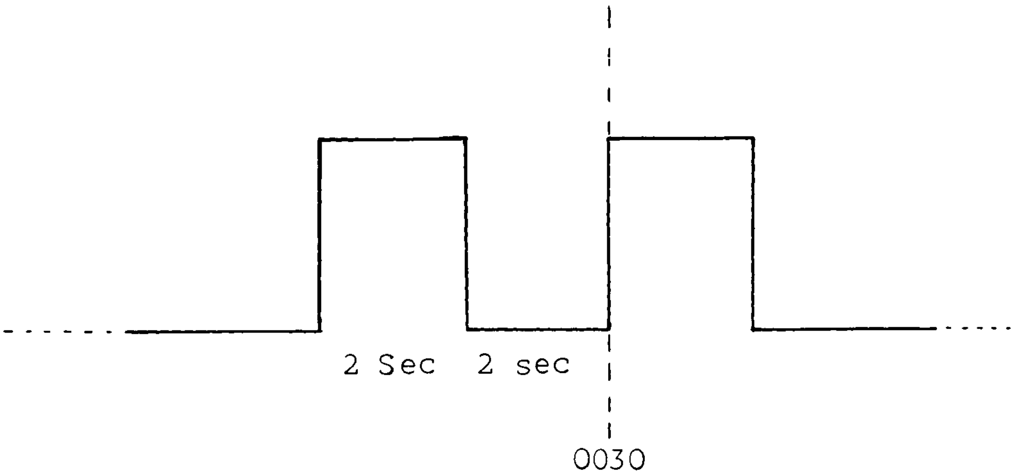


Fig. 4.1. TIMING PULSE TRAIN AT 0030

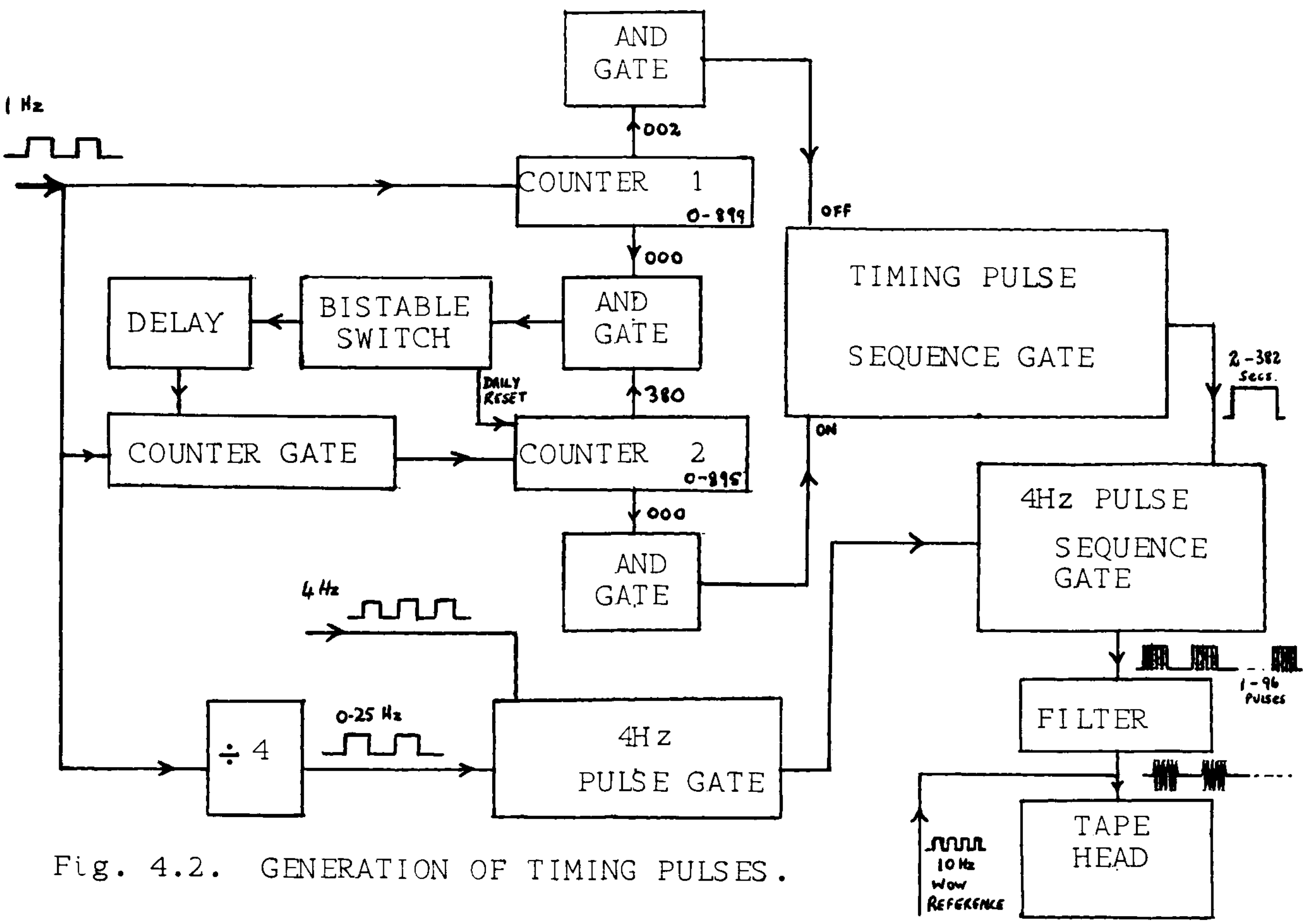


Fig. 4.2. GENERATION OF TIMING PULSES.

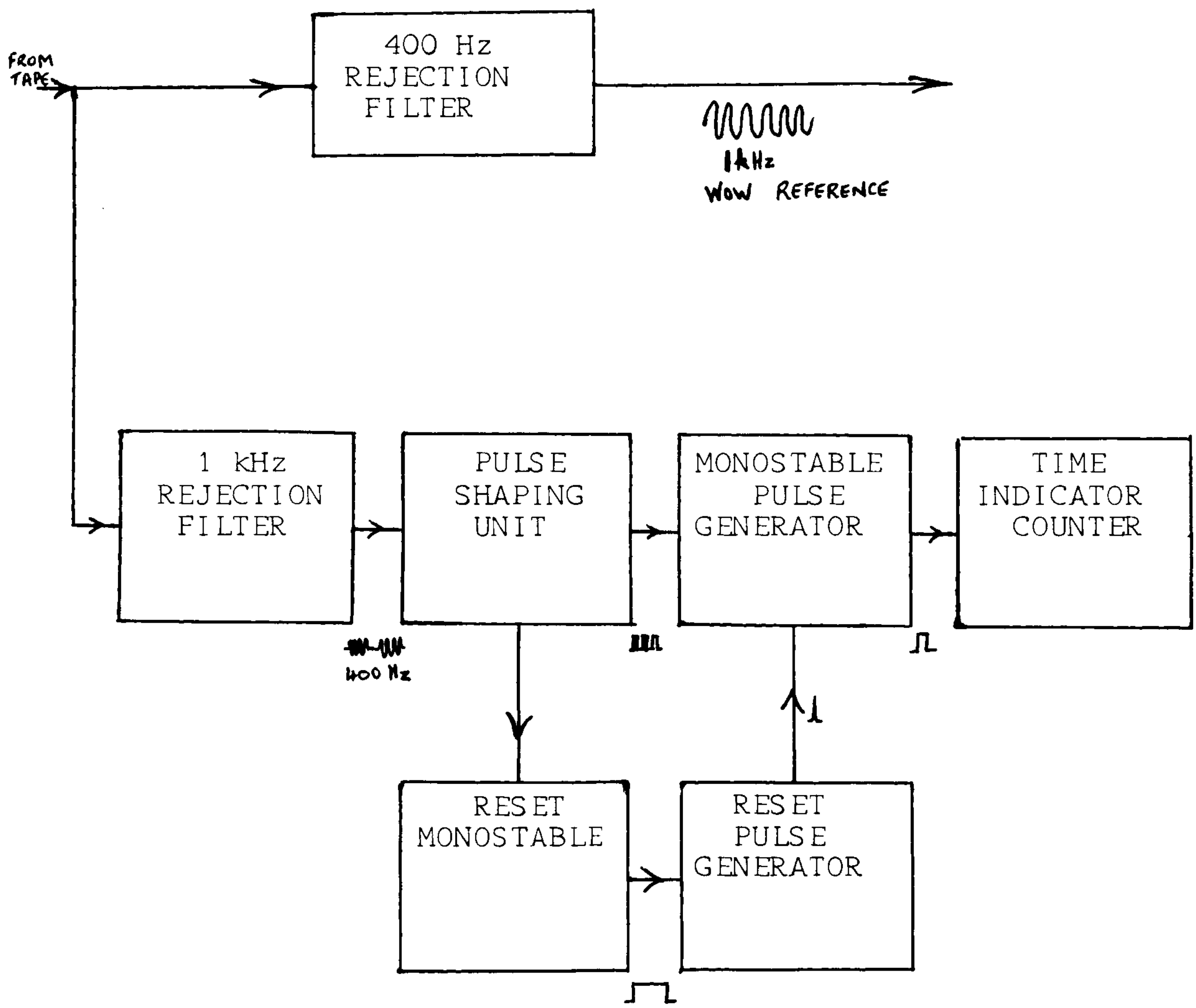


Fig. 4.3. RECOVERY OF TIMING PULSES FROM MAGNETIC TAPE.

III

COMPUTER PROGRAMS FOR DATA HANDLING

I.M. Brazier and J.S. Mainstone

Input

Five-hole data tape containing micropulsation signals in digital form is produced by the method outlined in II.2 of this report. The data tape, containing both binary information and coded information, is read into the University's GE 225 computer as normal five channel tape using a GAP program. The characters are first tested to be non-zero so that the tape leader of zeros can be ignored. Once a non-zero character has been received all characters are retained, as subsequent zeros are significant. The characters are next tested for being odd or even. If even, this indicates no hole in position 1 and thus an information character, whilst if odd, a special symbol which is further interpreted by the computer program. The basic steps in the GAP program are as follows.

Symbol	Operation	Operand	X	Remarks
	RPT			
	LDZ			
	BNN			
	BRU	*-1		
	SNA	19		
	BZE			
	BRU	*-4		
	BRU	B		
A	LDZ			Return point to read next character.
	BNN			
	BRU	*-1		
	SNA	19		
B	BOD			
	BRU	SYMBOL		Requires interpreting.
	BXH	1	0	
	BRU	SECOND		4 least significant bits.
	SLA	3		
	STA	FIRST		4 most significant bits.

Symbol	Operation	Operand	X	Remarks
	INX	1	0	
	BRU	A		
SECOND	SRA	1		
	ADD	FIRST		RECONSTITUTED 8 bit binary information.
	LDX	ZERO	0	
	-			further program steps.
	-			
	-			
	BRU	A		
SYMBOL	-			Interpretative Procedures.
	-			
	-			
FIRST	DEC	0		
ZERO	DEC	0		

In its present form the read-in routine has been used to reformat the data and punch on cards the decimal equivalents of the 8 bit binary information. These cards are then available for feeding in as data for computational programs.

Correlation Program

For comparison of the various components of micropulsations at one site with one another, or of signals from spaced stations, or indeed for comparison of any relevant geophysical parameter with the micropulsation data, a computer program written in GAP is available. The basic program will accept up to 500 values, on punched cards, of each of three variables A, B and C (in floating point), compute the appropriate mean and standard deviation of each as well as the auto-correlation from zero delay up to a specified number of time-lags. The cross-correlation for AB, AC and BC are calculated, again from zero delay to some specified number of time shifts, positive as well as negative.

An alternative form of this correlation program accepts up to 750 values of each of two variables A and B, producing the relevant auto- and cross-correlations.

Power Spectra Program

Having obtained samples of micropulsation signals it is convenient to analyse them in terms of power spectra, on the assumption that each sample represents a stationary time series. This assumption appears to be generally justified for the lower frequency pulsations in the Pc3 portion of the spectrum but not for Pc1 or other pulsations which exhibit marked changes in frequency in a time which is short compared with a typical sample length (see Section III (viii) of the Second Semi-Annual Report on this NASA Grant).

For a finite length of record which is sampled at equal intervals of time the (apparent) auto-covariance function can be computed using standard techniques. The power spectrum is the Fourier Transform of the auto-covariance function for samples containing up to 1,500 data values on punched cards. Use is then made of the hanning lag window to compute the cosine transform and to output the power spectrum, normalized to unit standard deviation.

Coherency and Power Spectra Fortran IV Program

When comparing two sets of (presumably) related data e.g. two components of the micropulsation disturbance at a given site, the first step in the analysis is generally to calculate the cross-correlation between the samples. The coherency may be found from this by taking both the cosine and sine transform (the complex quantity made up of these in-phase and quadrature components is the cross-power spectrum) and then computing cross-power spectrum ÷ geometric mean of the auto-power spectra. A program in Fortran IV to perform such calculations is available, but as yet the Queensland University GE225 cannot handle this program. A modified form of program in Fortran III is in preparation.

Acknowledgments

Mr. M.J. Burke of the staff of the Physics Department of the University of Queensland was responsible for the initiation of the GAP programs for correlations and power spectra.

Mr. Bill Cook of the Boeing Scientific Research Laboratories, Seattle, U.S.A. wrote the Fortran IV program for calculation of coherency.

IV

A SURVEY OF THE OBSERVATIONAL AND THEORETICAL ASPECTS OF HIGH FREQUENCY MICROPULSATIONS

J.S. MAINSTONE*

INTRODUCTION

In this review paper I shall be dealing with micropulsations which fit roughly into the Pc1 and Pi1 groupings according to the 1963 IAGA classification. Pc1 pulsations cover the range from 200 millicycles per second (mc/s) to 5 cycles per second i.e. periods from 5 seconds to 0.2 seconds, whilst the Pi1 classification extends from 25 mc/s to 1 c/s. The upper portion of the Pi1 band is of interest because it contains the microstructure associated with many of the characteristic night-time pulsation bursts, Pi2, formerly known as Pt's.

Under the heading of Pc1 there appear to be two distinct phenomena viz. "pearls" (also called h.m. emissions, micropulsation whistlers etc.), and quasi-continuous noise-band emissions; the latter have only recently received attention.

Pc1 MICROPULSATIONS

1. 'Pearl-Type' Pulsations

Sucksdorff (1936) coined the name "Pearl Necklace" to describe the characteristic appearance on chart records of pulsations which he had observed in the auroral region. The occurrence of these pulsations showed a maximum in the day-time. Dubrovsky (1959) at the IAGA meetings at Utrecht mentioned "PP" (Pulsating Pearls) having greatest frequency of occurrence at night, with the maximum about midnight, local time. Dubrovsky's results referred to a station at Ashkhabad, geomagnetic latitude 30°N. Troitskaya (1959) at the same IAGA meeting referred to "Pearls", and mentioned that the diurnal distribution of pearls in the polar regions showed several maxima. She pointed out that there was a difference between the pearls observed during magnetically quiet times and those found during the course of storms - these latter were given the name IPDP (Intervals of Pulsations of Diminishing Period). Typically the period of IPDP was found to change from ~ 10 seconds down to 1 second; all great storms during the I.G.Y. contained IPDP. A similar phenomenon, given the name "solar whistle", was reported by Duffus et al (1958).

* Presented by invitation at the Radio Research Board Symposium on Geomagnetic Micropulsations, Hobart, Tasmania, August 1965.

Benioff (1960) defined a class of micropulsations with periods 0.3 - 2.5 seconds as "Type A" oscillations, thus including most of the Pc1 range. For his Type A oscillations he found, at times, almost perfect correlation over a distance of 290 km, and fairly frequently, common activity for stations thousands of kilometres apart. Benioff's observations were made chiefly in California, and for this region he found the occurrence of Type A oscillations to be essentially nocturnal, rising rapidly after sunset and falling rapidly after sunrise. The maximum occurred just before sunrise; this was found to be quite different from the situation in Sweden, where Type A was present throughout the whole 24-hour period, with a maximum between 0700 and 1000 L.T. As the occurrence showed a rough inverse relation to sunspot number and as there was a tendency for a greater incidence of Type A when f_oF2 was a minimum, Benioff suggested that the ionosphere was in general opaque for these frequencies.

Troitskaya (1961) proposed that both PP and S.I.P. (Rapid Irregular Pulsations, now class Pi1) were caused by injection of clouds of charged particles into the high atmosphere; only when the magnetic field was quiet and the cloud not very dense were PP excited. Evidence was also cited of IPDP observed at the earth's surface when Sputnik II reported very sharp fluctuations in the intensity of the outer Van Allen belt.

Tepley (1961) introduced the term "hm emission", and also the subdivisions "narrow-line emissions" and "broad-line" emissions. A number of distinct hm emissions could occur simultaneously; narrow-line may exist for hours, broad-line for 5 - 30 minutes. Close correlation was found between the occurrence of hm emissions and PCA during magnetically quiet periods. Since PCA was attributed to solar proton streams, he suggested that hm emissions were generated by the interaction of solar proton streams with the geomagnetic field, the necessary interaction taking place only during magnetically quiet conditions. An attempt was made to explain hm emissions along the same lines as VLF emissions - travelling wave amplification produced by electron streams moving along a geomagnetic field line and transferring energy to an electromagnetic wave (Gallet and Helliwell, 1959). Now the frequency ratio VLF (5 Kc/s): hm emission (0.5 - 5 c/s) $\doteq$ the mass ratio m_{proton} : $m_{electron}$ i.e. Tepley argued that the proton stream energy may be imparted to an electromagnetic wave which would propagate hydromagnetically downwards. Further to this, proton streams in regions of greater geomagnetic field strength would generate hm emissions at higher frequencies. He considered Parker's (1958) model of a plasma stream infringing on a thin magnetic boundary sheath, setting up a growing wave. Very roughly the proton cyclotron frequency should be $\sim$ wave frequency of the hm emission. Now 0.5 - 5 c/s corresponds to the proton cyclotron frequency range for magnetic field strengths 33 - 330γ . For a dipole field this would give distances of 5 - 11 earth radii for the magnetic boundary sheath.

Bomke (1962) worked with the combined results of ground loop (vertical component) magnetic measurements, and electric field measurements made by Jungmeister (1959, 1960), to come to the conclusion that $\frac{E}{H} \sim 2$ or 3×10^5, indicating that the secondary sources of 1 c/s micropulsations are of the electric dipole type produced by electric space-charge pulsations in the lower ionosphere. The height calculated by Bomke was ~ 100 km i.e. the same as for flaming aurorae which were often seen to coincide with 1 c/s micropulsations which he detected in Maine. He further concluded that the secondary sources were often only 400 - 500 m in diameter.

Jacobs and Jolley (1962) produced evidence to suggest that pearls detected in mid-latitudes were observed progressively earlier at eastern stations, the onset of pulsation activity moving westward at $\sim 15^\circ$/HR. This led to the conclusion that either (i) the onset of pearls depends entirely on local time or (ii) there is an azimuthal drift of charged particles trapped in the geomagnetic field. If pearls are due to the drift of protons one would expect to observe them with the frequency of the mirror oscillations (in fact, about 50 times too large); also the drift rate is wrong.

Vozoff, Ellis and Garland (1962) concluded that pearls result from mixing two sinusoidally varying magnetic fields differing from one another by 0.01 to 0.1 c/s. They found that when a record of about 1 hour of pearls was analysed there was a pronounced tendency for the entire pattern to repeat itself after 145 sec or 10 "pearls". Power spectra showed peaks at 0.53 and 0.67 c/s, each of which shifted slightly from one sub-sample to another. They could not explain the 145 sec recurrence pattern but tried to explain the power spectrum peaks at 0.53 and 0.67 c/s in terms of MacDonald's (1961) Mode model.

The next step came with the discovery by Tepley and Wentworth (1962), Gendrin and Stefant (1962), and Mainstone and McNicol (1962), independently and almost simultaneously, of the spectral fine-structure of pearls viz. a series of repetitive wave-trains of rapidly increasing frequency.

Mainstone and McNicol pointed out that pearls with mid-band frequencies around 0.5 c/s on the Brisbane records had a spacing between successive upward frequency sweeps of about 160 - 170 seconds whereas those ≈ 1 c/s appeared to have a smaller sweep spacing, around 100 seconds. They also drew attention to the fact that the 145 second repetition rate for pearls noted by Vozoff, Ellis and Garland was not much different from the Brisbane figure for the sweep spacing.

Gendrin and Stefant showed that the product $f_m t$ (i.e. mid-band frequency in c/s $\times$ sweep spacing in seconds) was approximately constant. For their stations at Chambon and Tromsø they found a mean value of 110, and this was also the value which could be inferred from the results of Vozoff, Ellis and Garland.

Wentworth and Tepley (1962) postulated that since X-ray bursts and PP occurred simultaneously after sudden commencements, the same bunch of fast electrons, oscillating along the field lines, might be responsible for both phenomena. On this model the hm emissions were attributed to the diamagnetism of an electron bunch, the emission frequency being associated with the bounce period between mirror points. The rising frequency was said to be connected with acceleration of the electrons, but this point was not elaborated or clarified.

Lokken, Shand and Wright (1962) reported that signals in the 1 c/s range have appreciably lower amplitudes in the auroral zones than in mid-latitudes. They came to this conclusion after studying records from 2 northern auroral stations, 2 mid-latitude Canadian stations, and a station in the Antarctic. Heacock and Hessler (1962), discussing chart records of pearls at the auroral zone station at College, Alaska, stated that any of the College pearl-type events could be broken down into component "pearl necklaces" which add to produce a complicated wave-form. They do not seem to have been fully aware of the significance of the discovery of the spectral fine-structure of pearls.

Lokken, Shand and Wright (1963) made a study of the electromagnetic background around 1 - 2 c/s and concluded that there exists a 'white' continuum having a mean peak-to-peak level of $\sim$ 0.3 mγ. The presence of regional lightning increases the signal strength, so that they concluded that the source of the continuum is world-wide lightning. On the continuum there are superimposed regular and impulsive disturbances; these can exceed the background by up to 60 db or more. In dealing with pearls they cited an instance when the beginnings, peaks and ends of active periods did not in any way correspond at their stations, Great Whale, Churchill and Victoria in Canada, and Byrd Station in Antarctica. The occurrence was first recorded exclusively in the auroral zones and there continued longer than at Victoria. However, when the development was most spectacular, the amplitude at Victoria was much greater than at the auroral zone stations. For a short time at the height of this development the degree of similarity of the records at all 4 stations was remarkable; however, it was noted that Byrd appeared to be displaced with respect to the other 3 by half the time between successive bursts.

Santirocco and Parker (1963) tackled the question of the power spectrum of a wide range of Pc-type micropulsations recorded in Bermuda, and showed that over the whole range of frequencies there was a smooth background curve decreasing monotonically with a slope of - 6 db per octave, on top of which was superimposed a mass of variable fine structure. The signals in the 1 c/s region were $\sim$ 55 db down on those at 10 mc/s, or $\sim$ 22 db down on 100 mc/s.

Schlich (1963) analysed chart records taken at Kerguelen, and in France and South Africa. His conclusion was that the frequency of oscillation decreases with increasing latitude, the maximum frequency of oscillation for a station being determined by the geomagnetic latitude. He also found a relation such that the frequency increased as the intensity of the main field increased.

Yanagihara (1963) made use of the auroral zone results of Lokken, Shand and Wright to show a phase shift of 180° between events observed simultaneously in opposite hemispheres. Gendrin (1963) proposed a fast proton bunch model to explain pearls; the rising frequency was explained by a latitude spread in the bunch at the time of the particle injection. In this case the structure periodicity had to be associated with longitudinal drift. A similar explanation was given by Heacock (1963).

Jacobs and Watanabe (1963) postulated a model in which slow proton bunches bounced back and forth along the geomagnetic field lines. According to this model the slow proton bunches excite resonant oscillations in the lower magnetosphere, the structure periodicity being associated with the proton bounce period. The rising frequency comes about because of a latitude variation of the characteristic resonance frequency in the lower magnetosphere. Although the slow proton bunch hypothesis would account for the 180° phase shift between hemispheres quite satisfactorily, it would also predict that the frequency should increase with geomagnetic latitude, something which was not observed.

Jacobs and Watanabe (1964), following a suggestion of Obayashi, showed that the sequence of rising tones in pearl structure could be explained readily in terms of dispersion in the propagation of a hydromagnetic wave packet guided along a geomagnetic field line. The name "micropulsation whistlers" which was coined by Lokken, was used to describe this guided wave propagation. Whereas V.L.F. whistlers represent propagation along the magnetic field in one mode (right-handed) which has a cut-off near the electron gyro frequency and produces a falling frequency characteristic, micropulsation whistlers, which propagate in the other mode, have the opposite dispersion.

Tepley (1964) produced evidence that hm emissions can occur simultaneously at widely-spaced stations with the same period and regular repetition, but that the signal amplitude <u>decreases</u> with decreasing latitude (the discrepancy between this result and the earlier result of Lokken, Shand and Wright (1962) points to the fact that the geological environment of the stations concerned could well be a dominant factor.) At equatorial stations Tepley sometimes found a structure-doubling on Sonagram displays, suggesting superposition of waves from opposite hemispheres propagated across the equator.

Pope (1964) drew attention to the difficulty of measuring polarization of pearls in a meaningful manner because of the superposition of rising tones in the spectral structure.

Wentworth (1964) considered the diurnal variation of occurrence of pearls and decided that the observed times of maximum activity viz. during the day in the auroral zones and at night in middle latitudes are consistent with an afternoon maximum of production of pearl activity at all latitudes, modified by an ionospheric shielding effect. Wentworth also claimed that hm emissions are more likely to occur in the seven days following a geomagnetic storm than in magnetically quiet periods.

Meanwhile Obayashi (1965) extended the ideas of Jacobs and Watanabe to show that hydromagnetic whistlers originate somewhere between 60^{o} and 65^{o} geomagnetic latitude and that the initiating wave is triggered by spontaneously injected high energy ($\sim$ 100 keV) protons, generating anomalously Doppler shifted cyclotron radiation. The wave is amplified by a slow beam of particles ($\sim$ several keV) through travelling-wave interaction. He also suggested an alternative initiation due to relativistic electrons. Once the mechanism is excited, propagation within the ionosphere, or below it, to lower latitudes is envisaged.

Heacock and Hessler (1965) carried further the investigation of the relation between pearl events and magnetic storms by showing that for College, Alaska, an S.S.C. is generally followed by a pearl event, especially between 1200 and 2000 L.M.T. The most prominent pearl events seem to follow S.S.C.'s preceded by very quiet magnetic field conditions. They reported that whereas Pi1 and Pc3 activity appear precisely at the reported S.S.C. time, there is a delay of 2-3 minutes between S.S.C. and the onset of pearl activity. Further to this there occurs an increase in the average Pc1 frequency at times of S.S.C.

Tepley, Heacock and Fraser (1965) gave some preliminary results of spaced-station observations of hm emissions. On some occasions it is possible for these emissions to exhibit almost identical frequency-time characteristics over a great geographical extent, although the signal amplitudes are not necessarily comparable at all 4 stations. On rare occasions events observed simultaneously at College and Palo Alto showed entirely different characteristics. In general the signal at Kauai resembles the signal at College (on the same geomagnetic meridian) more closely than does the signal at Palo Alto, much closer to Kauai. The authors noted that the longitude effect indicated by this may be associated with local time, or possibly with the location of the signal source above the ionosphere.

At the ANZAAS Congress in Hobart in August, 1965 Dowden showed that the theory of micropulsation whistlers can be used to allow measurements of exospheric plasma density in regions hitherto almost inaccessible by normal V.L.F. methods. Manchester stressed that propagation attenuation along the ionospheric duct in and above the F region can be very important in determining day to night changes in pearl activity. Mainstone reported that Pc1 records from Brisbane show a concentration of activity mainly below 1 c/s; this is not unlike the situation prevailing in auroral regions but quite different from most other mid-latitude stations.

2. Noise-Band Emissions

A broad-band emission in the Pc1 frequency range was reported by Gendrin and Stefant (1962a). It was most prevalent in the auroral zones during nights of strong auroral activity, though there was not a close correlation between the two phenomena. Mainstone (1963) gave details of a similar "noise-band" found on the Brisbane records. In this case there is a regular diurnal variation in frequency (for details see the other paper by Mainstone in this report). Comparison of records from the Brisbane area and the Melbourne area indicate that the band has a lower frequency at the higher latitude. However Tepley and Amundsen (1965) reported that their records taken at a number of spaced-stations indicate the presence of "continuous sub-ELF emissions", with a higher frequency at higher latitudes. The origin of the noise-band emissions is not at all clear, though Tepley and Amundsen favour high-level generation as a broad spectrum of hydromagnetic waves which are modified in the lower exosphere as they propagate downwards to the observing station, whilst Mainstone suggests a connection with mirroring particles in the radiation belts.

Pi1 MICROPULSATIONS

A good summary of the work on Pi1 pulsations has been given by Troitskaya (1964). From this review it appears that S.I.P., or Pi1, generally form part of the microstructure of isolated bays and Pi2, are observed mainly in the early morning and late at night, and are closely connected with auroral intensity variations. Results from Lovozero indicate that there are two maxima in the S.I.P. distribution, the first connected with S.I.P.'s forming the fine structure of slow disturbances, and second with S.I.P. excitation on the background of a comparatively quiet field.

Campbell and Matsushita (1962) found that the intensity of S.I.P. at College is $\sim$ 10 times as great as in California, and that there is a maximum of occurrence at the equinoxes. Brown and Campbell (1962) established that X-ray bursts and S.I.P. have comparable oscillation periods and the two practically coincide - a 1 minute delay is not uncommon. The association of S.I.P. with the aurora and X-ray bursts has led to the suggestion that S.I.P. are due to pulsating currents at E-layer heights caused by injection of charged particles (Troitskaya, 1964).

SOME UNANSWERED QUESTIONS

I feel that there are several aspects of Pc1 activity, particularly, which should be investigated. Perhaps some of these could be borne in mind when future experiments are planned and when records are being analysed:-

(a) Accurate measurement of the frequency sweeps of individual rising tones at spaced stations, for simultaneous events.

(b) Quantitative results on the variation of amplitude with latitude, preferably in at least the H_V, H_{NS} and H_{E-W} components, and in E_{NS} and E_{EW} as well, if possible.

(c) How much do the different values of f_oF2 at widely-spaced stations affect Pc1 bursts observed simultaneously at these stations?

(d) Is it possible to measure a propagation velocity?

(e) Proper measurements of polarization.

(f) A check on Bomke's results for 1 c/s sources.

(g) How important is the local time effect?

(h) Variation of activity with the sunspot cycle.

(i) Measurements of time variations of plasma density using Dowden's methods.

Undoubtedly there are many more unanswered questions which we in this part of the world could tackle, either individually or on a co-operative basis.

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V

THE FREQUENCY SPECTRA OF MICROPULSATIONS RECORDED AT STATIONS IN EASTERN AUSTRALIA

J.S. Mainstone

1. INTRODUCTION

According to the 1963 IAGA classifications, geomagnetic micropulsations cover the range of periods from 600 seconds to 0.2 seconds, i.e, frequencies from about 1.5 millicycles/sec to 5 cycles/sec. In order to record satisfactorily almost the whole of this range of frequencies on magnetic tape, it is convenient to use a tape speed of $2\frac{1}{4}$"/hr. The upper frequency limit, determined chiefly by the gap sizes of the recording and replay heads, is then ~ 1.5 c/s. The low frequency response deteriorates rapidly as the effective length of contact between the tape and the pole pieces of the replay head exceeds $\lambda/2$, where λ is the recorded signal wavelength on tape. For a typical head with a contact length of $\frac{1}{8}$", λ-crit~$\frac{1}{4}$", so that for a tape speed of $2\frac{1}{4}$"/hr this corresponds to a signal frequency of 9 cycles/hour or 2.5 mc/s. Thus an interval of more than $2\frac{1}{2}$ decades, or 9 octaves, of micropulsation signals is available for analysis when the tape is replayed at conventional tape speeds into a Kay Sonagraph or Raytheon Rayspan audio spectrum analyser. For the production of Sonagrams (assuming a Sonagraph frequency sweep of 0-8 Kc/s) replay at 30"/sec, representing a speed-up of about 44,000 times, is suitable for daily displays of Pc3 and Pi spectra, whilst replay at $3\frac{3}{4}$"/sec, a 5,500 times speed-up, gives Pc1 or "pearl" event spectra.

For the purposes of spectral analysis the University of Queensland has set up equipment at Toolangi, near Melbourne, Victoria and Townsville, North Queensland, as well as the base station at Esk (near Brisbane).

2. THE Pc3 SPECTRUM

(i) DIURNAL BEHAVIOUR: The Pc3 spectrum at each station is markedly variable from day to day. However, the activity can be resolved into two main components, viz., a component which varies diurnally and another which is related to the degree of geomagnetic agitation. When the K_p index is essentially constant during the whole of the day the highest frequencies present in the spectrum appear around midday (Fig. 1). Changes in K_p from one 3-hour interval to another generally produce a modulation of this basic diurnal variation (Figs. 2 and 3)

(ii) TEMPORAL AND SPATIAL VARIATIONS: Sudden commencement or cessation of Pc3 activity, or sharp interruptions at times of otherwise continuous occurrence, are a feature of the daily Sonagrams. That these are real effects is shown by the fact that the same pattern can occur in detail at Esk and Toolangi (Figs. 4 and 5), and also at Townsville. At the Esk station both the H_{N-S} and H_{E-W} components are recorded, the other stations recording H_{N-S} only. The Sonagrams and chart records from Esk indicate that the activity is often highly polarized, and it is not always the H_{N-S} spectrum which shows the best detailed similarity to the spectra for Toolangi and Townsville.

(iii) Pc3 AND MAGNETIC INDICES: In order to test statistically the relationship between the frequency range covered by Pc3 on the daily Sonagrams and magnetic K-indices, the interval 1000-13 00 E.A.S.T. was chosen - this corresponds to 0000-0300 U.T. or the 1st daily K_p period. Pc3 pulsations are present during this time every day on the Toolangi Sonagrams, even if at times they are rather weak and might be hard to detect on chart records; also, the sun is then nearest the zenith (one would hope that this represents the least complicated situation). A total of 211 consecutive days from November 2, 1962 to May 31, 1963 was included in the analysis. Correlations with the magnetic indices K_p and K-sum, K_T (the Toolangi K index) and K_{T-SUM}, and A_p were tested.

To summarize the results: Each of the correlations is significant to better than the 0.1% level. The correlations between Pc3 frequency and K_p, K-sum, K_T and K_{T-SUM} are each greatest for zero delay. On the other hand the correlation with A_p reaches a maximum for a delay of 1 day, the sense of this delay being such that A_p for the day following gives best correlation with the Pc3 for a particular day. The same thing occurs when A_p is tested for correlation with the other magnetic indices.

It is clear from this that the frequency band covered by Pc3 pulsations is a sensitive indication of the general level of geomagnetic disturbance as measured by the conventional parameters. Since a continuous record of the Pc3 spectrum is obtainable quite simply it seems reasonable to suggest that this represents a very convenient method of monitoring the "strength" of the solar wind, since Snyder, Neugebauer and Rao (1963) have already demonstrated a high correlation between measured solar wind plasma velocity and the value of K_p.

The lag of a day in the case of A_p seems to indicate that the larger amplitude magnetic disturbances (which affect the linear index A_p much more than the logarithmic K index) take some time to build up and decay. This may be evidence for the continuous existence of a ring current.

(iv) GEOGRAPHICAL EXTENT OF CORRELATION: The same daily micropulsation data from Toolangi have also been compared with the K figures from Macquarie Island (geomagnetic latitude 60^{o}S) on the edge of the southern auroral zone, and Port Moresby (geomagnetic latitude 18^{o}S) as well as Toolangi (geomagnetic latitude 47^{o}S). These magnetic observatories lie within ± 12° of the same geomagnetic meridian. The maximum Pc3 frequency present between 1000-1300 h E.A.S.T. on the Toolangi Sonagrams was tested for correlation with each set of K figures for the corresponding period of time, and the daily K-sum for each station was also used in a similar manner.

The correlation coefficient for Pc3 vs K figure is almost identical for the K figures from Toolangi and Port Moresby viz. 0.66 and 0.65 respectively for the 211 pairs of values, whereas it falls to 0.43 for the Macquarie Island K figures. The same trend is indicated by the correlations with the K-sum values for each place, viz. 0.61 for both Toolangi and Port Moresby, 0.50 for Macquarie Island.

These results are perhaps a little surprising in that Macquarie Island and Toolangi are separated in geomagnetic latitude by less than half of the separation between Toolangi and Port Moresby. We may conclude either, that the predominant day-time Pc3 activity at Toolangi is caused preferentially by a low- and middle-latitude phenomenon (possibly related to the Sq current system?), or that a part of the K figure variation at Macquarie Island is due to local auroral-type phenomena which are in turn associated with Pc4 and Pc5 but not with Pc3, and part with a more widespread phenomenon.

On this evidence alone, therefore, it is not possible to decide whether or not the auroral zones represent the primary locations of Pc3 activity.

(v) Pc3 AND THE IONOSPHERE: During the times of magnetic storms, ionospheric storms may develop and f_oF2, the critical frequency of the F region, may fall considerably. It is natural, then, to ask whether the Pc3 frequency spread correlates negatively with f_oF2. Various workers, e.g., Duffus (1960), have shown vague general connections of this type between Pc3 and the F region.

For a period of some 16 days in each of May, August and November, 1962 hourly values of the Pc3 maximum frequency at Esk were compared with f_oF2 from Moggill, a Brisbane suburb. As expected, the hourly values of these two parameters when averaged over the whole of each sample show similar diurnal variations, i.e., in this sense there is a high positive correlation between the average behaviour of the two, the interpretation being simply that there is a common source for the electromagnetic and corpuscular radiation reaching the earth. However, when representative times of 0300, 0900, 1500 and 2100 h E.A.S.T. are considered, the cross-correlations for the three samples show erratic behaviour being sometimes positive, sometimes negative, but in any case not significant. Thus, by this test, Pc3 activity and f_oF2 appear to be unrelated.

When this analysis was repeated, firstly with f_oE_s and then with h'F as the ionospheric parameter, in each case the results once again indicated a lack of any relationship. This does not, of course, rule out the possibility that much smaller height and electron density variations in the ionosphere are related to Pc3 activity as is suggested by the small frequency variations ($\sim$1 in 10^7) measured for WWV transmissions over distances of a few thousand kilometers by Fenwick and Villard (1960), and Davies, Watts and Zacharisen (1962).

(vi) MAGNETOSPHERIC 'MEMORY': There is evidence that detailed fine-structure in the Pc3 spectrum may retain its identity for several days. For instance, at about the same time on two successive days (September 28 and 29, 1963) the same fine-structure in the daily onset of Pc3 activity is seen on the Toolangi records (Figs. 6 and 7). In each case the Sonagram shows an unusual situation in that the Pc3 starts with the higher frequencies and then extends downwards at a uniform rate to the lower frequencies (a range of about 30 mc/s) in some 20-30 minutes. Other examples of this type have been observed, particularly during magnetically-active periods. Since a 24-hour periodicity in the incident solar wind is rather unlikely, it seems that evidence is accumulating for the "freezing-in" of a disturbance configuration in the magnetosphere (possibly due to plasma injection), which then determines the Pc3 frequencies which can be excited by the solar wind. The Sonagram records suggest that such a disturbance retains its identity for a maximum of 2-3 days only.

(vii) LONG TERM CHANGES: The regular production of daily Sonagrams at Esk began in May, 1962. At that time there was little evidence of any distinct bands in the Pc3 spectrum (Fig.8). Later in 1962, and increasingly during the succeeding years, it became clear that the Pc3 Sonagrams generally possessed a fine-structure (Figs. 9 and 10), which was also seen on the Toolangi records (Fig. 11). That this is not due to the equipment used for recording is evidenced by the fact that similar frequency bands are visible on Sonagrams produced from very different equipment at Seattle, U.S.A. (Fig.12). The frequency bands on the Brisbane records typically show little variation over many days although relatively sudden ($\sim$ an hour) changes occur from time to time (Figs. 13 and 14).

(viii) SOLAR FLARE EFFECT: A detailed study has been made of the micropulsations associated with the solar flare at about 2358 U.T. on September 20, 1963. As the flare occurred around 1000 h E.A.S.T. the Toolangi and Esk stations were in a favourable position to observe any related micropulsation phenomena. The Toolangi daily Sonagram (Fig.15) shows very weak Pc3 activity, typical of a magnetically quiet period, during the hours prior to the flare. Coinciding with the flare event there is a sudden onset of strong Pc3 which then lasts until about 1730 h E.A.S.T. i.e., roughly sunset time.

The chart records of the magnetic components and earth currents at Esk show large amplitude disturbances of short duration coincident with the flare, similar to those reported by previous workers. The Esk Sonagram shows that weaker Pc3 activity continued for a further 2-3 hours, but not as long as for Toolangi.

3. THE Pc1 SPECTRUM

(i) 'PEARLS': During the period May, 1962 to January, 1964 a total of 217 well-defined bursts of Pc1 occurred on the H_{N-S} records from Esk. Of these, 138 (or 64%) were between local midnight and 0900 h, 74 (or 34%) between 1500 h and midnight, whilst only 5 (or 2%) were detected between 0900 and 1500 h. The peak of the diurnal activity appears to be at about 0200-0300 h (Fig. 16). This result is in general agreement with the findings of other workers for this latitude. Wentworth (1964) believes that there is a maximum production of this type of pulsation above the afternoon hemisphere of the earth and that the observed diurnal variation of occurrence is due to the shielding effect of the ionosphere.

It was shown by several workers simultaneously, including Mainstone and McNicol (1962), that the frequency spectrum of Pc1 consists of a series of rapid upward frequency sweeps over a limited, well-defined range (Figs. 17 and 18). The mean or mid-band frequency at Esk during the May 1962 - January 1964 period lay between 0.3 c/s and 1.1 c/s, with a peak of occurrence at 0.6 c/s (Fig. 19). There is also some evidence of a band apparently centred on the 1.4 to 1.6 c/s region but because of an upper limit of about 1.8 c/s imposed by the method of recording and analysis, the information on this possible second band is scant.

From Sonagrams of Pc1 recorded at stations near Brisbane between September, 1961 and November, 1962, the midband frequency, f_m, and the spacing, t, between each frequency sweep were estimated for each occurrence of the pulsations, together with the product f_mt. The fact that the product f_mt remains relatively constant even though f_m varies over a wide range of frequencies was first observed by Gendrin and Stefant (1962). Their results were for stations at Chambon-la-Forêt (geomagnetic latitude 50°N) and Tromsø (geomagnetic latitude 67°N); the mean value of the product f_mt for these stations is 110 whilst our results, spanning roughly the same period of time, give a mean value of 92. The extreme values in the case of the Queensland records are 68 and 110 whereas the upper and lower limits given in the analysis by Gendrin and Stefant are 66 and 137. There may be a latitude dependence involved, although the restricted frequency range of the Brisbane equipment possibly causes a bias towards the Pc1 with lower midband frequencies.

In a paper by Gendrin (1963) observations from College Alaska and Chambon are compared and it is clear that the College records (obtained from charts, not Sonagrams, unfortunately) show lower midband frequencies and greater sweep spacings, although the product f_mt for College appears to give a value around 100 also.

Various authors e.g. Jacobs and Jolley (1962), have suggested that the occurrence of Pc1 is a local-time phenomenon, and have produced some evidence to show the westward progression of Pc1 bursts at about 15° of longitude per hour. It is noticeable that on our records very often bursts of Pc1 appear on consecutive days, something like 24 hours apart, which would lend some weight to this proposition.

In the paper by Gendrin (1963), quoted above, he shows a Sonagram of a good Pc1 burst occurring at Chambon between 0400 and 0440 U.T. on August 14, 1962. The midband frequency is 0.75 c/s and the sweep spacing is 180 sec. A burst of Pc1 lasting for about 45 minutes and with a midband frequency of 0.7 c/s occurs on the Esk records at 0540 E.A.S.T. on August 14, 1962, i.e., 1940 U.T. on August 13, 1962 (Fig. 20). As this is a relatively isolated burst on the Esk records very similar in general characteristics to that recorded at Chambon about $8\frac{1}{2}$ hours later, it is tempting to conclude that the two disturbances have a common origin - if this is so the westward drift of the burst is about 17° per hour which is in agreement with the results quoted by Jacobs and Jolley.

However, one interesting point arises, viz., the sweep spacing for this burst as recorded at Esk is about 120 seconds, whereas at Chambon it is 180 seconds. If the ideas put forward by Obayashi (1965) are correct, this result would imply that either a guided hydromagnetic wave packet, and/or a group of particles, shifts towards a slightly higher geomagnetic latitude during the $8\frac{1}{2}$ hours. Obayashi's figures would seem to indicate a latitude shift of about 2°, or a change in L-value of about 0.6.

(ii) <u>NOISE BAND</u>: The micropulsation records from Esk show a characteristic noise band centred at about 250 mc/s (Figs. 21 and 22). During daylight hours the band becomes quite diffuse but at night is much better defined. It is then confined to say 100 mc/s to 500 mc/s. An inspection of a series of consecutive day's records shows clearly that there is a diurnal variation in the frequencies contained in the noise band. The well-defined night-time band reaches its maximum frequency between midnight and 0400 h E.A.S.T. with a distinct preference for the earlier time during the winter months.

A comparison between the maximum frequency attained each day and the magnetic disturbance index K-sum fails to suggest any relationship. Similarly the time of occurrence of the maximum frequency is apparently independent of magnetic activity. However, the cross-correlation between the maximum frequency and K-sum for 2 samples covering the months June to December, 1962 and March to June, 1963 respectively indicates that although there is no correlation for zero delay, there is a consistent correlation (between 1% and 2% level of significance) for a delay of -3 days and for +5 or 6 days, i.e., a K-sum change appears to produce a noise band change some 3 days later or alternatively a noise band change leads to a K-sum change 5 or 6 days later. The auto-correlation functions for the two parameters fail to reveal any 8 or 9 day periodicity.

In spite of the accumulation of a considerable quantity of data on the characteristics of the noise band, its origin is still uncertain, though it would seem possible that particles trapped in the inner radiation belt could be responsible. From time to time irregular impulsive disturbances occur in the noise band, of the same general form as those detected by Bowman and Mainstone, (1964) after the nuclear explosion at Johnston Island on July 9, 1962 and these are interpreted as being due to particle dumping.

The diurnal frequency changes may arise from diurnal movements in latitude of the radiation belt. The fact that the Toolangi records show a noise band of predominantly lower frequency than that at Esk suggests that if the hypothesis is correct the radiation belt drifts northward during the night until some time after midnight, then moves southward again - such movements of high latitude aurorae are of course not uncommon and a similar effect has been shown to occur with the outer radiation belt (O'Brien, 1963).

Tepley and Amundsen (1965) have recently reported a similar noise band which appears on the Sonagrams from their stations.

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CAPTIONS FOR FIGURES

Figure 1. Sonagram of Pc3 activity, Esk, 8th August, 1962. K_p constant at 4 - 5 throughout the day.

Figure 2. Sonagram of Pc3 activity, Esk, 15th August, 1962. K_p changed abruptly from 3 (prior to the 10 - 13 h period) to 5 during this day.

Figure 3. Diurnal variation of period of Pc3 as read from chart records at Esk.

Figure 4. Sonagram of Pc3 activity, Esk, 26th November, 1962.

Figure 5. Sonagram of Pc3 activity, Toolangi, 26th November, 1962.

Figure 6. Sonagram of Pc3 activity, Toolangi, 19th September, 1963. The onset of the main activity at about 0530 should be noted.

Figure 7. Sonagram of Pc3 activity, Toolangi, 30th September, 1963. The onset of Pc3 at about 0500 should be compared with that at 0530 on the previous day, 29th September, 1963 (Figure 6).

Figure 8. Sonagram of typical Pc3 activity, Esk, May, 1962.

Figure 9. Sonagram of Pc3 at Esk showing frequency band structure, 4th November, 1963, H_{N-S} component.

Figure 10. Band structure in Pc3 activity; Esk telluric recording (E_{E-W}).

Figure 11. Band structure in Pc3 activity; H_{N-S} component at Toolangi.

Figure 12. Pc3, H_{N-S} component, recorded at Seattle, showing clearly the banded structure.

Figure 13. Sonagram showing variation of band frequencies, Esk, 31st July, 1964.

Figure 14. Changes in frequencies of band structure, Toolangi, 10th March, 1963.

Figure 15. Sonagram of daily Pc3 activity, Toolangi, 21st September, 1963.

Figure 16. Distirbution of occurrence of Pc1 (Pearl) bursts, H_{N-S} components at Esk, May, 1962 to January, 1964.

Figure 17. Sonagram of Pc1 (Pearl) event.

Figure 18. Sonagrams of Pearl events observed simultaneously at Esk and Toolangi (Note: the time scales for the two sonagrams are not equal).

Figure 19. Distirbution of Pc1 Mid-band frequencies, H_{N-S} component at Esk, May, 1962 to January, 1964.

Figure 20. Comparison of Pc1 bursts at 1940 U.T. on 13th August, 1962 at Esk (lower) and at 0400 U.T. on 14th August, 1962 at Chambon (upper, taken from Gendrin, 1963).

Figure 21. Sonagram showing frequency variation of noise-band at ~ 250 - 500 mc/s, Esk, H_{N-S} component, 13th October, 1962.

Figure 22. Variation of noise-band frequency over a period of about 12 hours centred on midnight, L.T. Reproduced from a Rayspan Analyser record.

5

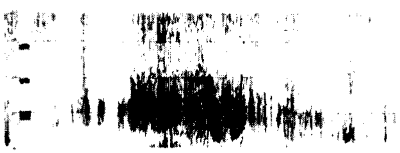

FIG. 1.

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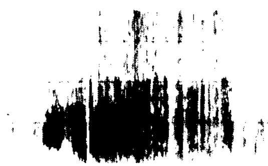


FIG. 2.

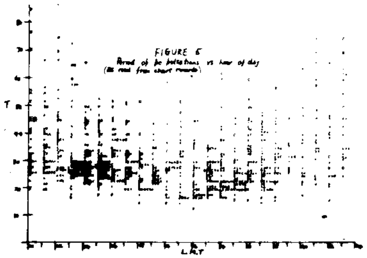


FIG. 3.

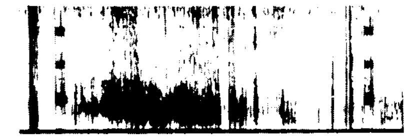


FIG. 4.

FIG. 5.

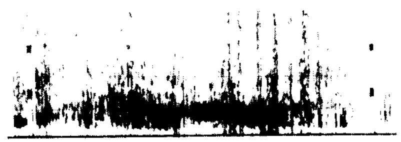


FIG. 6.

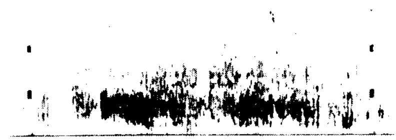
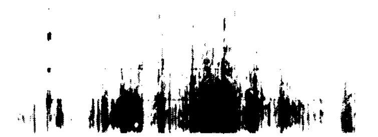


FIG. 7.



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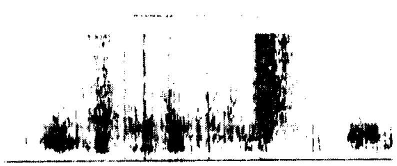

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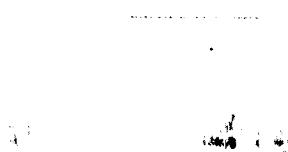

FIG. 10.

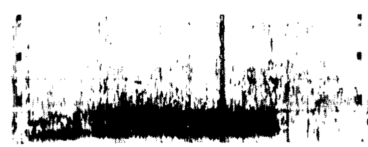

FIG. 11.

FIG. 12.

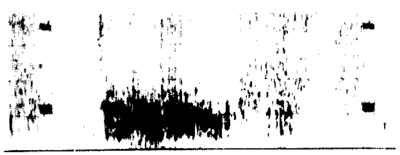

FIG. 13.

FIG. 14.

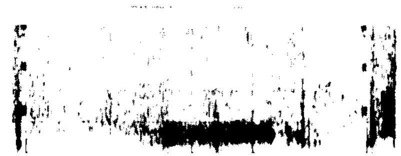

FIG. 15.

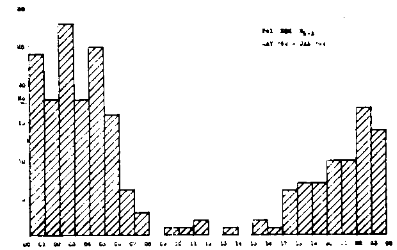

FIG. 16.

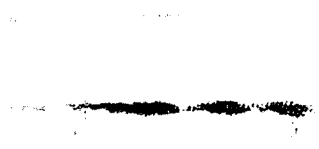

FIG. 17.

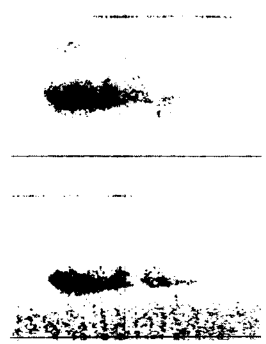

FIG. 18.

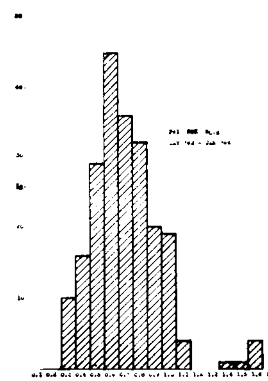

FIG. 19.

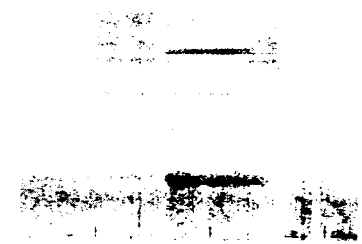

FIG. 20.

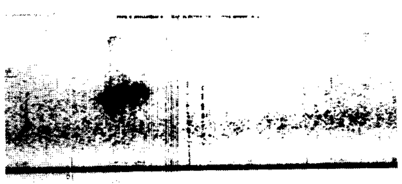

FIG. 21.

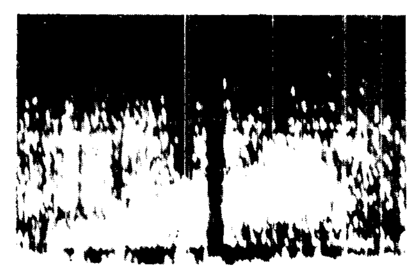

FIG. 22.

VI

MAGNETO-TELLURIC SIGNALS RECORDED SIMULTANEOUSLY AT CLOSELY-SPACED STATIONS IN SOUTH-EAST QUEENSLAND

R.E. Dunlop and I.M. Brazier

This study was initiated for the two-fold purpose of (i) obtaining information regarding the propagation of the micropulsation-producing disturbance and, (ii) investigating the effects of local geology on magneto-telluric signals.

Although data has been published recently* pertaining to (i), the experiment to be described is substantially different from that of Herron. Further, a systematic study of local geological effects will be of considerable importance in the field of micropulsation research. In the area chosen for this study, the geology is relatively simple but changes uniformly along one direction. Figure 1 shows the geographical and geological location of the recording sites. Over underlying sandstone, a wedge-shaped layer of basalt extends westwards from Toowoomba (140 km from the coast line). The thickness ranges from about 300 metres to effectively zero at the most distant recording station.

Magneto-telluric signals were recorded in two directions (N-S) and (E-W) at each of two sites simultaneously. In order to obtain such simultaneous records, all four signals were recorded on the one magnetic tape, the two channels from one station being telemetred to the other station, where all information was recorded.

Base Station Equipment

The essential features are shown in Figure 2. Signals were obtained from three lead (Pb) probes, placed to give the North-South and East-West components of the magneto-telluric field. One probe was common to each direction and is used as the earth point for all the station equipment. Signals of the order of millivolts were obtained with probe spacings of approximately 150 metres. Since all the sites used in this experiment were on farms, the probe spacings varied depending on local buildings etc. Telephone wire was used to connect the probes to the work hut and since these were prone to breakage (wind and farm animals being the worst offenders) the first unit to which these were connected was a probe continuity tester (Fig. 3) in which a D.C. potential could be switched to two of the probes in turn. This unit also contained a power failure indicator.

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* Herron, T.J.: J.G.R. 11, 5, 871 February 1, 1966.

In order to eliminate noise (mainly 50 Hz signal from the power lines) and the higher frequency components the signal was passed through a low pass R-C section with a cut-off frequency of 330 mHz and a 50 Hz rejection filter. The circuit is shown in Figure 4. Attenuation at 50 Hz is about 60 db.

With the large signal obtained, a simple balanced transistor chopper amplifier (Fig. 5) was sufficient to drive the following circuitry. The gain of these amplifiers was about 65 db over the range 20 - 100 mHz; the response fell off below 20 mHz because of the input capacitive coupling.

The following filter unit (Fig. 6) had a flat passband from 10 to 100 mHz, with 12 db/octave roll-off on either side. Outputs from the filter provided signal for chart monitoring and for the voltage-controlled oscillators which were described in the third semi-annual report of May, 1966.

The V.C.O.'s operated at frequencies of 270 and 400 Hz. Frequency deviation was set to $\pm 7\frac{1}{2}\%$ for an input signal of 1 millivolt peak-to-peak. The square wave outputs were filtered through a series of R.C. filters and the resulting sine-waves mixed and used to amplitude-modulate the output of a 55.3 MHz transmitter. The power delivered to the three element Yagi antenna was about 30 watts which proved to be more than sufficient for telemetring over the distances used. This frequency (one of the few very high frequencies available) had one major disadvantage, that of television interference. For this reason data was recorded from about 11 p.m. until 3 p.m. only.

To facilitate operating procedures and calibration each station was equipped with a radio telephone operating on 6 MHz. Both stations were manned continuously during recording periods.

Mobile Station Equipment

This equipment was housed in a caravan to allow easy transportation to the various recording sites. All circuitry for the recording of local signals was identical to that described in the previous section. The extra equipment required for the telemetry reception and subsequent data recording is shown schematically in Figures 7 and 8.

After detection, the modulating signal was passed through two audio pass band filters to separate the carrier frequencies. These were then demodulated (Fig. 9) and fed into chart-driving amplifiers for monitoring purposes. For tape-recording the filter outputs were clipped; at this stage all four signal components were in the form of frequency-modulated square-waves. Three R-C low-pass networks filtered off most of the harmonics in each track, and after mixing with a bias signal were recorded on magnetic tape moving at 15 inches per minute. The output from a fixed frequency oscillator (300 Hz) was also mixed with one of the 400 Hz carriers; the use of this signal for "wow" correction is discussed elsewhere in this report (Chapter II.1).

Experimental Data

Data has been recorded from four different mobile site positions, shown in Figure 1. The reconstruction and digitization of the signals are discussed in Chapter II of this report. Automatic data processing under development will allow power spectra, coherencies and correlations to be computed.

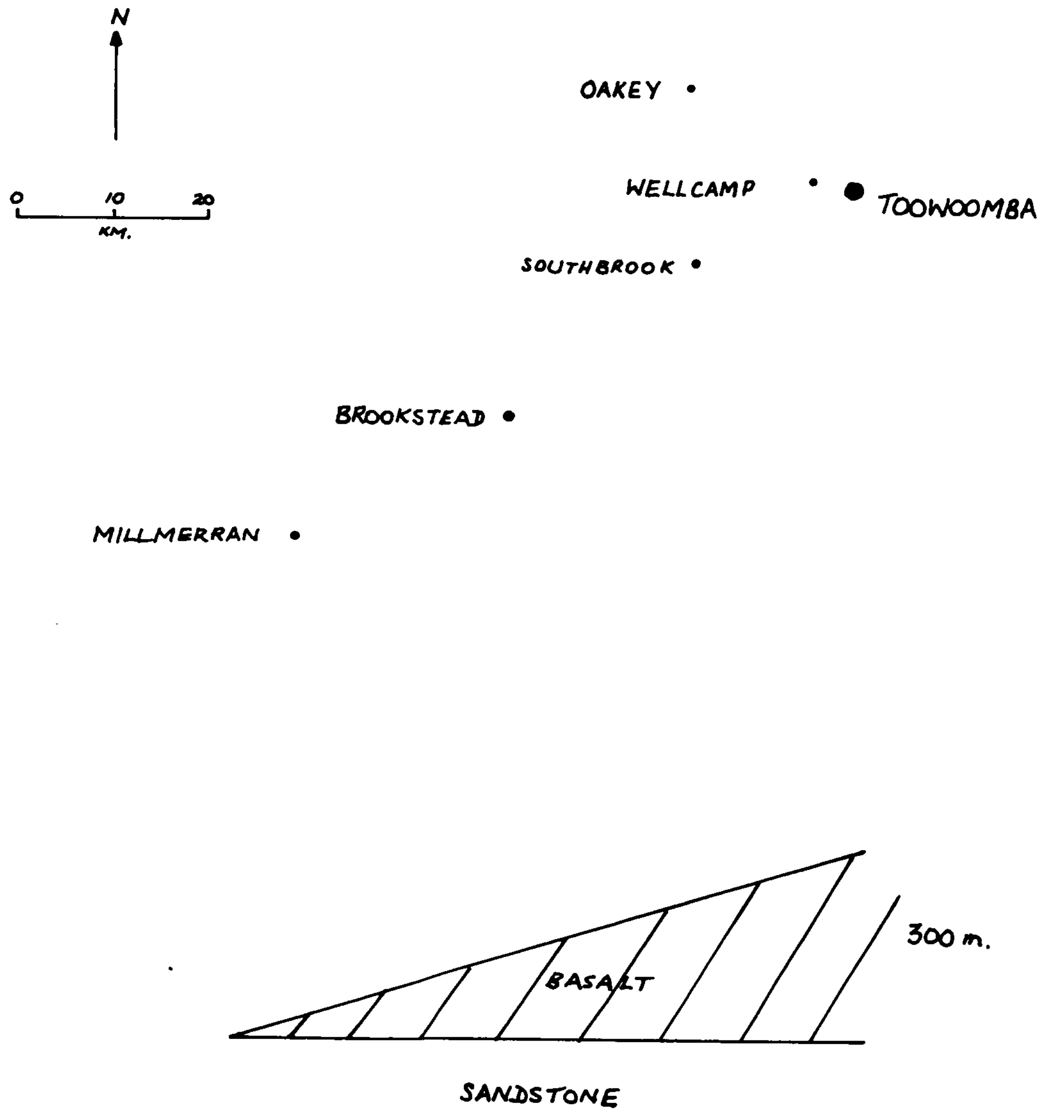


FIG. 1. GEOGRAPHICAL & GEOLOGICAL MAPS OF RECORDING SITES.

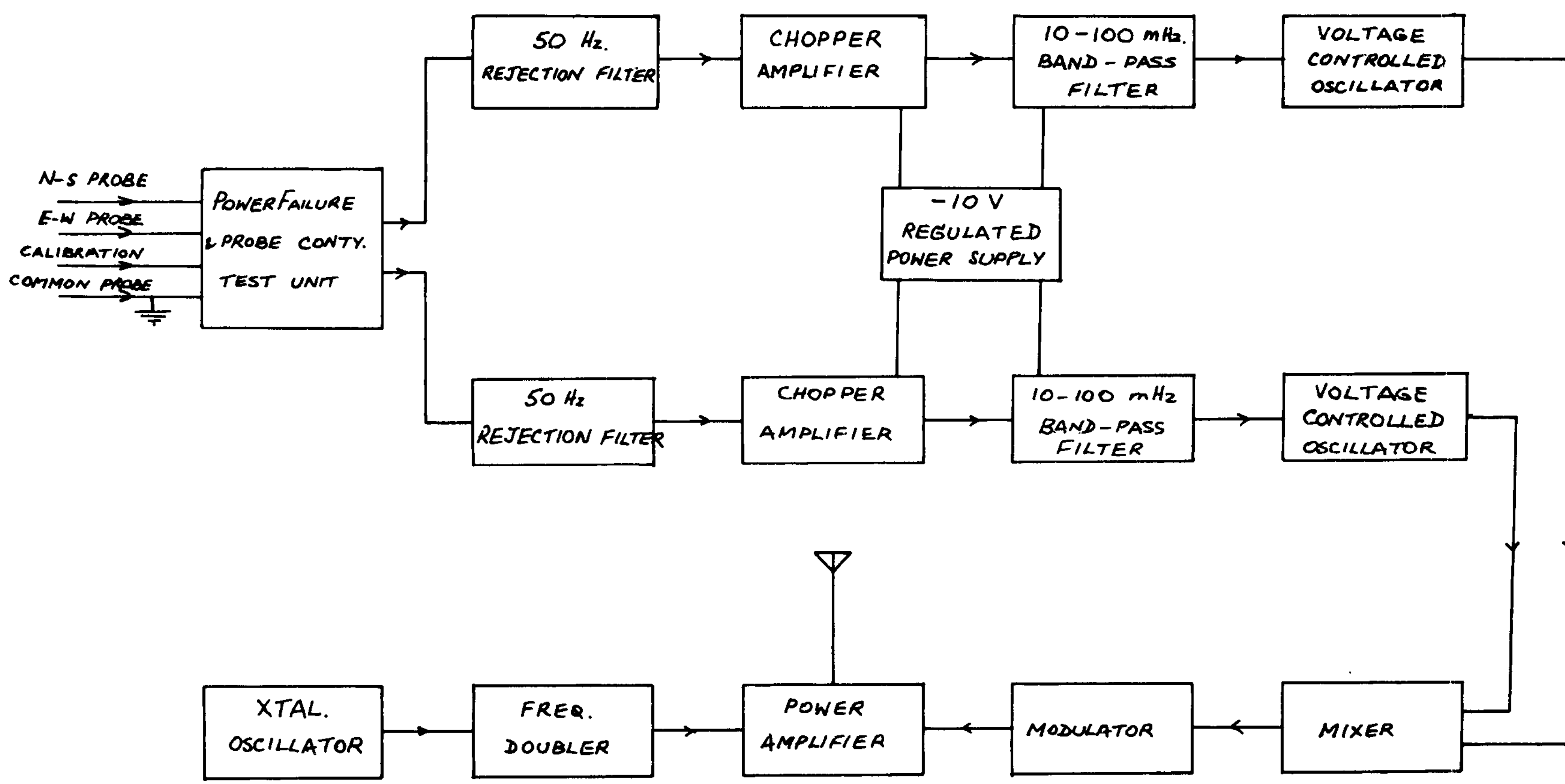


FIG. 2. BASE STATION EQUIPMENT.

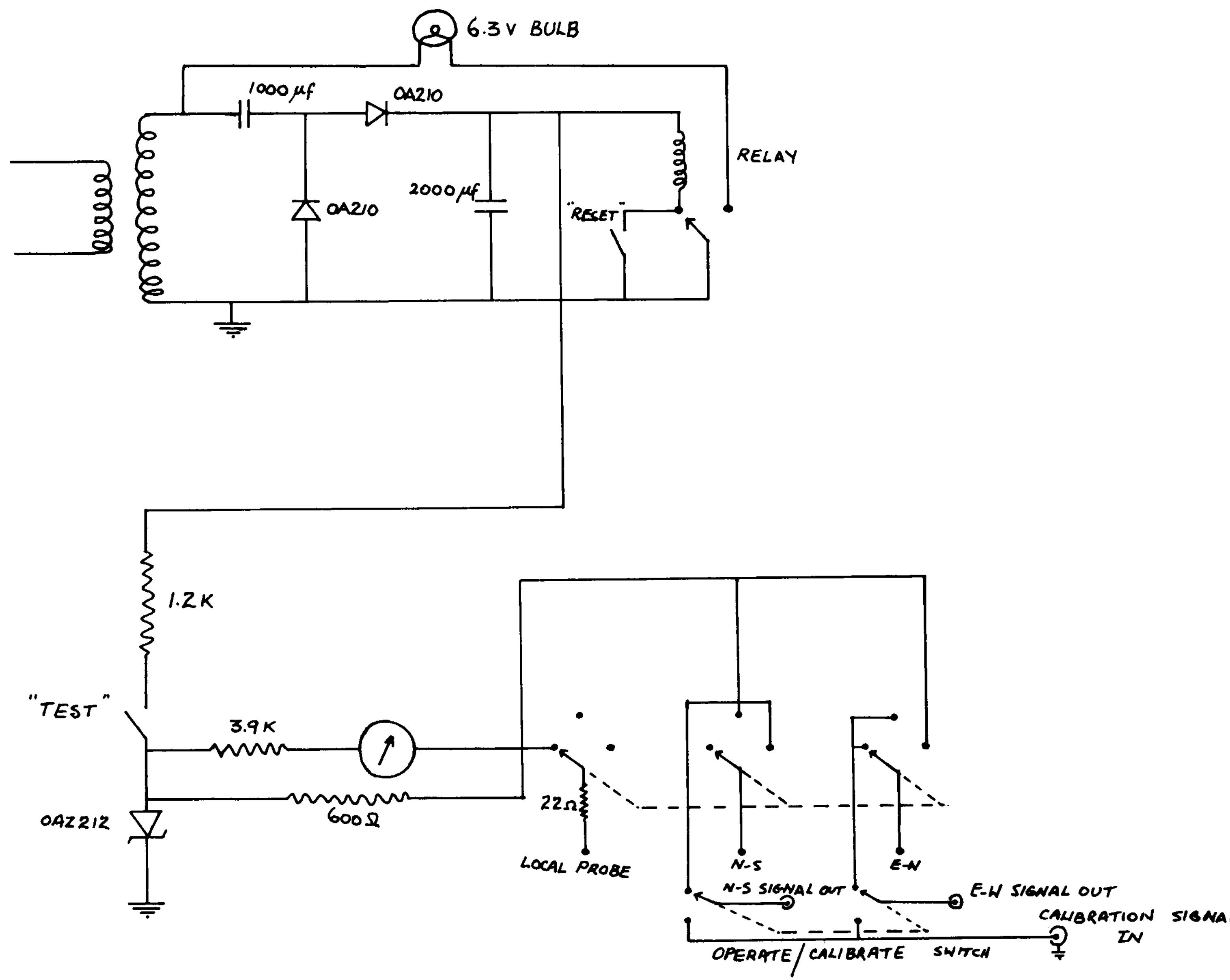


FIG. 3. POWER FAILURE AND PROBE CONTINUITY TEST UNIT.

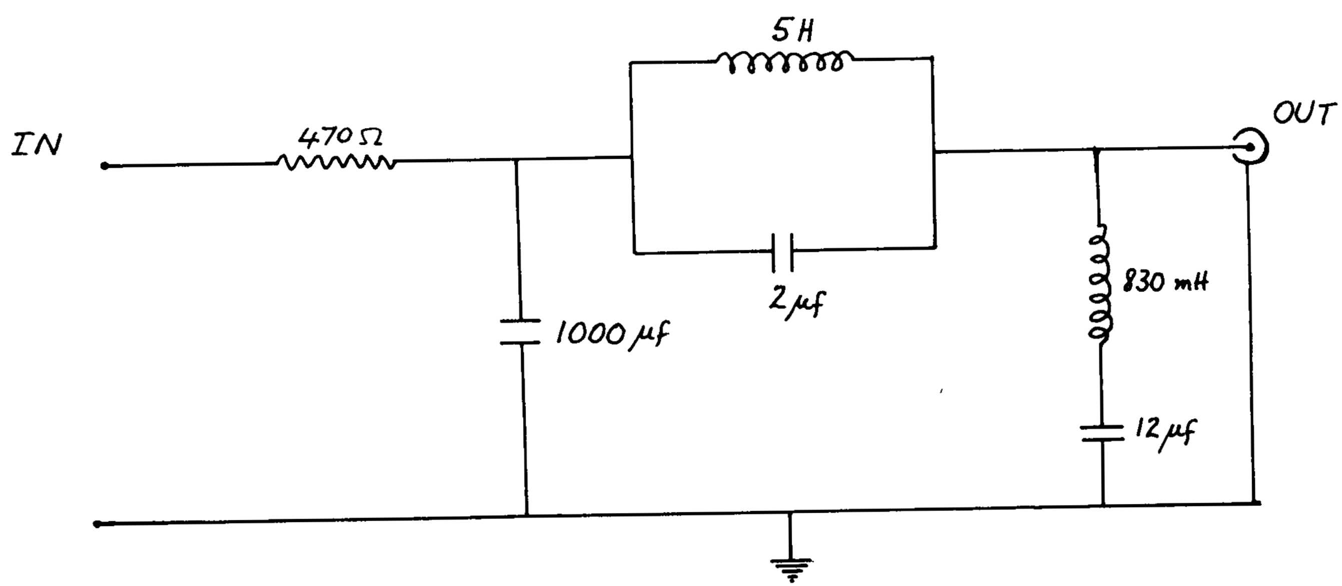


FIG. 4. LOW PASS AND 50 Hz REJECTION FILTERS.

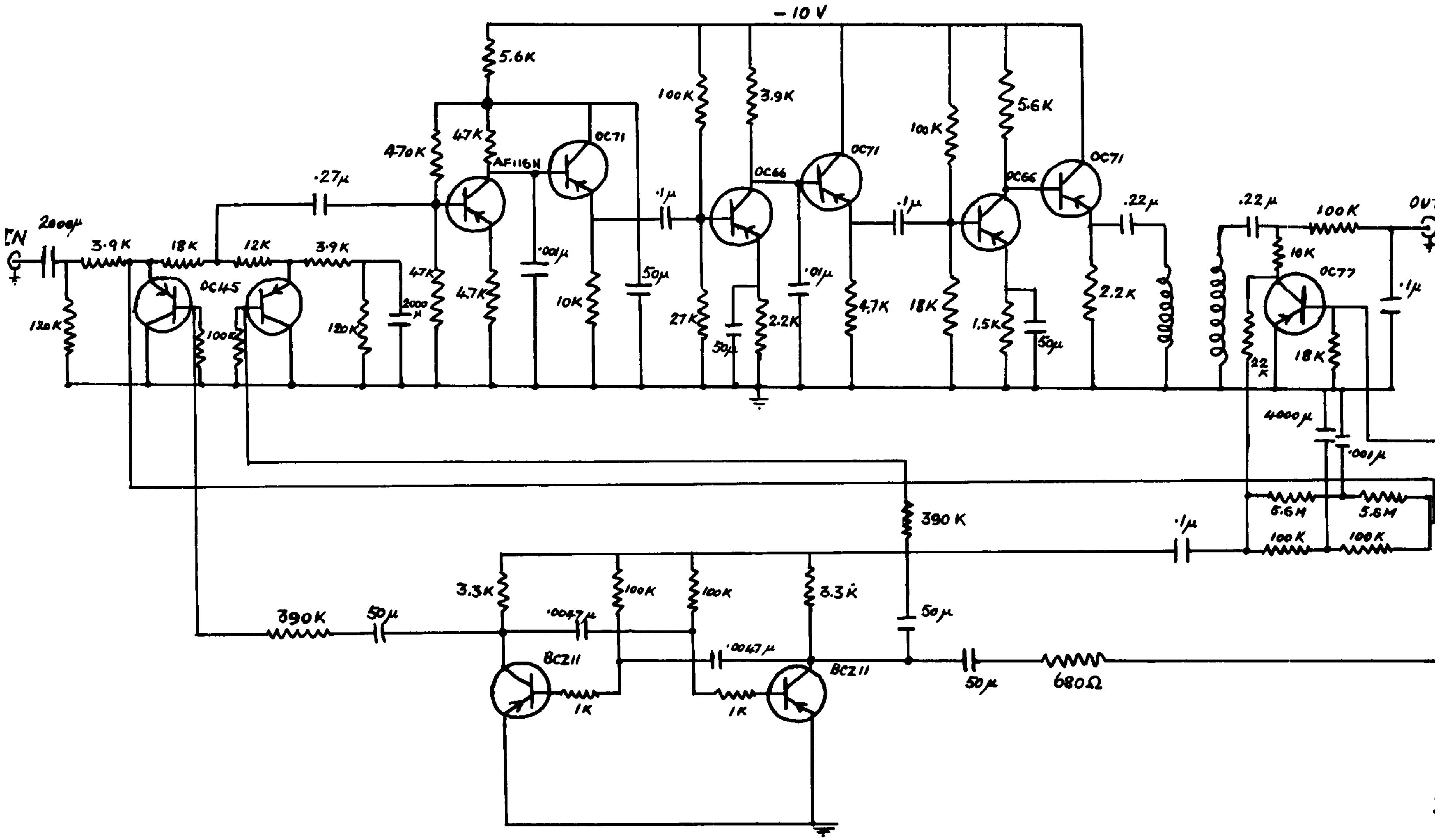


FIG. 5. BALANCED TRANSISTOR CHOPPER AMPLIFIER.

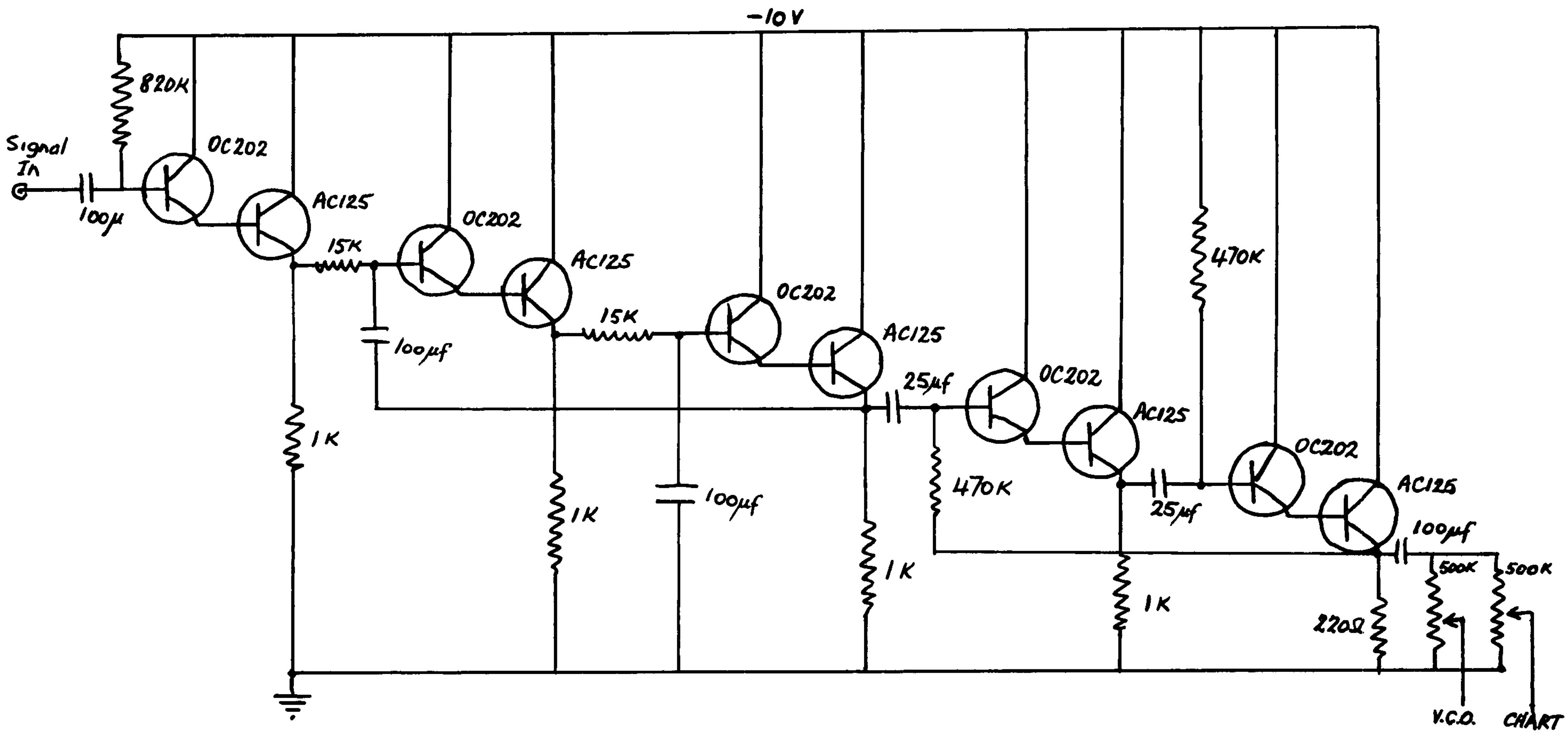


FIG. 6. 10 - 100 mHz BAND-PASS FILTER.

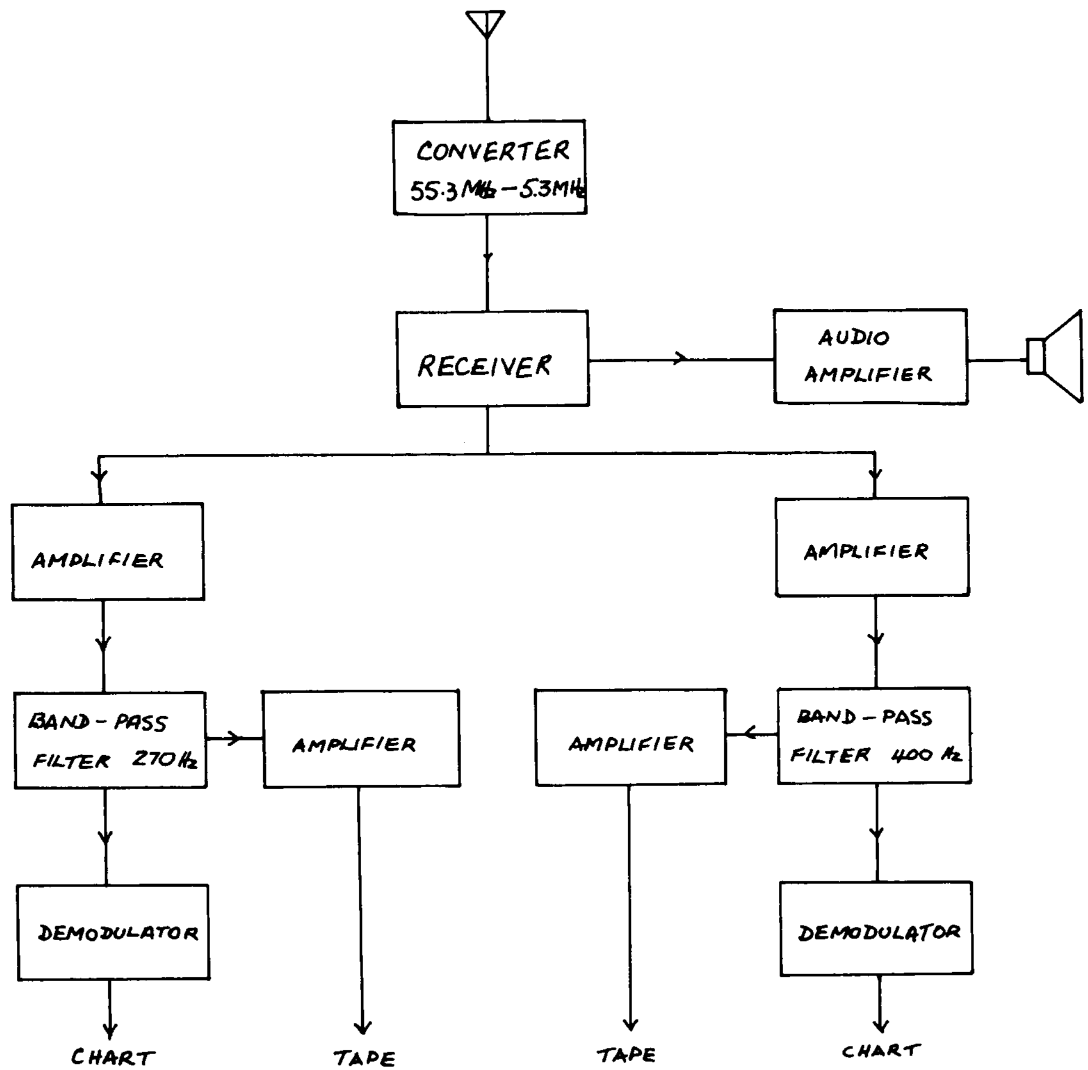


Fig. 7. RECEIVING AND DEMODULATING EQUIPMENT.

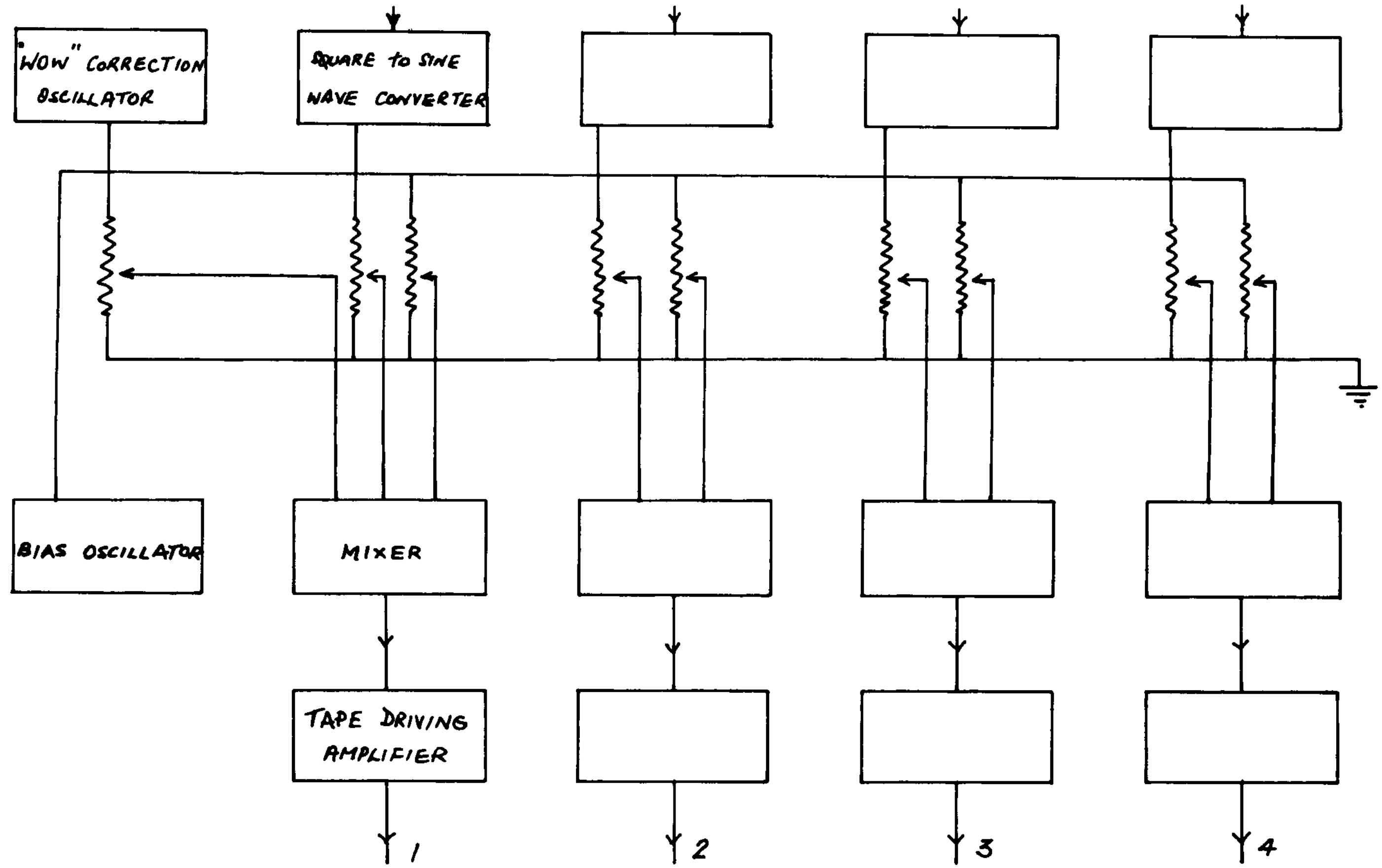
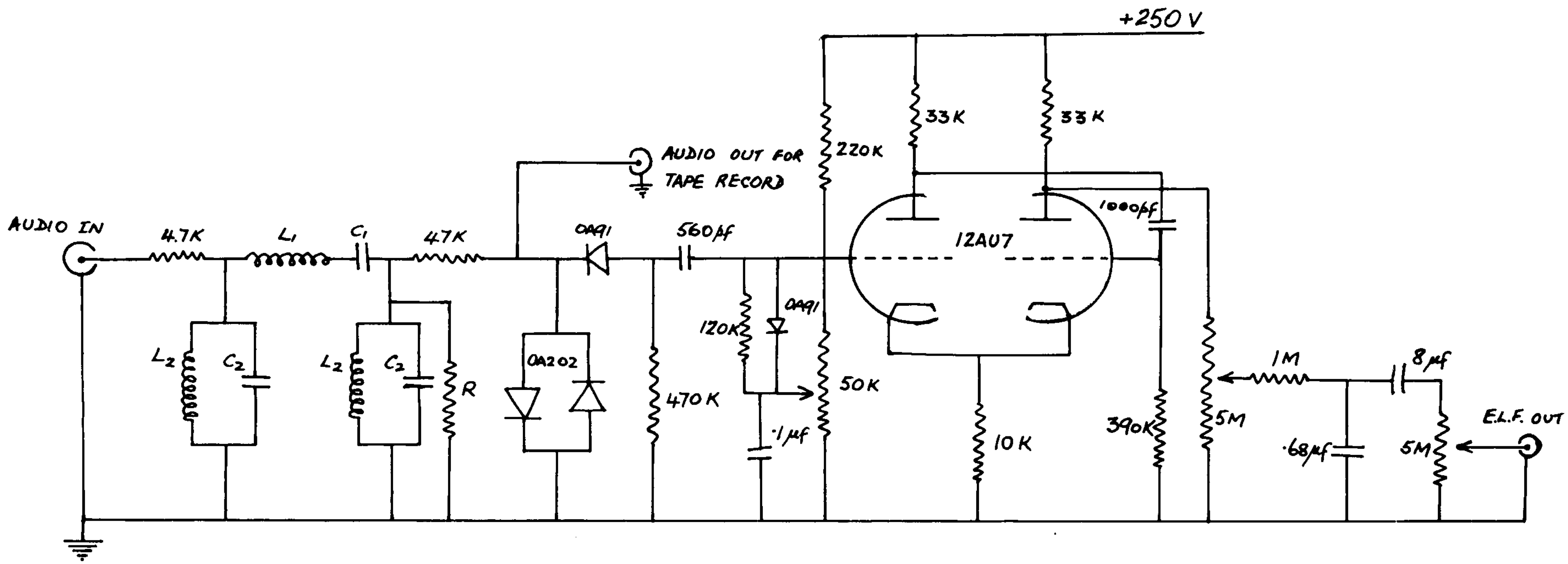


FIG. 8. RECORDING EQUIPMENT.



FOR 270 Hz $L_1 = 1.55\ H$, $C_1 = 0.22\ \mu f$, $R = 700\ \Omega$

$L_2 = 96\ mH$, $C_2 = 3.6\ \mu f$

FOR 400 Hz $L_1 = 8.0\ H$, $C_1 = 0.02\ \mu f$, $R = 2.2\ K$

$L_2 = 156\ mH$, $C_2 = 1.0\ \mu f$

FIG. 9. AUDIO BAND-PASS FILTER AND DEMODULATOR.